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The role of task relevance in saccadic responses to facial expressions

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Abstract

Recent research on healthy individuals suggests that the valence of emotional stimuli influences behavioral reactions only when relevant to ongoing tasks, as they impact reaching arm movements and gait only when the emotional content cued the responses. However, it has been suggested that emotional expressions elicit automatic gaze shifting, indicating that oculomotor behavior might differ from that of the upper and lower limbs. To investigate, 40 participants underwent two Go/No-go tasks, an emotion discrimination task (EDT) and a gender discrimination task (GDT). In the EDT, participants had to perform a saccade to a peripheral target upon the presentation of angry or happy faces and refrain from moving with neutral ones. In the GDT, the same images were shown, but participants responded based on the posers' gender. Participants displayed two behavioral strategies: a single saccade to the target (92.7%) or two saccades (7.3%), with the first directed at a task-salient feature, that is, the mouth in the EDT and the nose-eyes regions in the GDT. In both cases, the valence of facial expression impacted the saccades only when relevant to the response. Such evidence indicates the same principles govern the interplay between emotional stimuli and motor reactions despite the effectors employed.

KEYWORDS
attention, emotional facial expressions, Go/No-go task, saccades, task relevance

INTRODUCTION

How do affective stimuli impact motor behavior? Do they induce automatic reactions, or do their influence depend on contextual relevance and individuals' goals? Traditionally, emotional stimuli, especially threatening ones, were believed to steer selective attention, prioritize their processing, and trigger automatic reactions.[1–3] The rationale was that quick emotional responses enhance survival chances. The motivational model formalizes this concept,[1,2] suggesting emotional stimuli activate two systems: appetitive in positive contexts and defensive in threatening situations. However, the empirical evidence does not fully support this hypothesis.[4–7] Recent studies strongly indicate that the valence of emotionally charged stimuli impacts motor behavior in healthy individuals only when relevant to the task.[4–15]

In our laboratory, the behavioral reactions of the same individuals to identical emotional pictures were assessed using two versions of a Go/No-go task: an emotion discrimination task (EDT) and a Gender Discrimination Task (GDT). In the EDT, the presence of an emotion was crucial for the correct answer, while in the GDT, emotions were task-irrelevant, and participants responded according to the posers' gender. Motor responses were consistently influenced by stimuli valence only when task-relevant (i.e., in the EDT), with differences disappearing in

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task-irrelevant contexts (i.e., in the GDT). It is worth stressing that this experimental design allowed for the assessment of identical emotional stimuli and motor responses in task-relevant and task-irrelevant contexts without requiring explicit perceptual judgments from participants. In fact, unlike most prior studies where participants were asked to assess face valence or respond to specific expressions, we instructed them to move based on the presence or absence of emotional expressions without explicitly categorizing them. We never asked participants to move for specific emotions like fear or happiness or to label the expressions. Our approach enables participants to process face images by simply determining whether any emotion is present, which is sufficient for deciding whether to move. This is notable as it is widely acknowledged that the visual signals employed for guiding motor actions are processed differently from those bringing to perception.[16]

Furthermore, the observed impact of emotional stimuli in previous studies could be ascribed solely to the valence of the stimuli, as the stimulus arousal was meticulously controlled, and there were no stimuli perceptual differences except those linked to the emotional expressions. In all cases, participants had to respond by moving their limbs while their eyes were unrestricted and not recorded. However, when using the eyes as effectors, the impact of task relevance may differ. This is because some studies suggest facial expressions trigger automatic gaze shifts toward diagnostic features associated with specific emotions.[17–19] In a study by Gamer and Büchel,[19] participants had to classify emotional faces by pressing a key while their eyes were monitored. Images were shown for 150 ms and presented so that observers' initial fixation was either on the eye or mouth region. Under these conditions, participants could perform just one saccade after the stimulus offset. The authors evaluated whether a saccade was performed and, in this circumstance, where the gaze was directed. Reflexive saccades happened approximately 25% of the time, with their direction influenced by the emotion displayed. When fixating on the eyes, gazes shifted more toward the mouth for happy expressions, while fixating on the mouth led to more gazes toward the eyes for neutral and fearful faces. Hence, these automatic saccades were highly sensitive to the distribution of diagnostic facial features. Scheller et al.[17] extended this result, demonstrating that the above-described gaze behavior remained consistent even in passive viewing or GDTs, where emotional valence was task-irrelevant. As in the Gamer and Büchel[19] and Sheller et al.[17] studies, saccades were performed after the stimuli offset; they could not allow for extracting information from these stimuli. Thus, the authors suggested that such eye movements reflect a preattentive mechanism automatically detecting emotional facial features and facilitating attention orientation.

Bodenschatz et al.[18] supported this idea by showing that unconsciously perceived facial emotions prompt reflexive saccades toward diagnostic regions. They showed emotional faces as prime stimuli for 50 ms and asked participants to report the valence of a neutral facial expression presented right after the prime. Despite no affective priming effect on subsequent judgments of the neutral stimuli, the emotional primes elicited automatic gaze shifts to the eye and mouth region of the neutral face after a fearful and a happy facial expression, respectively.

To investigate whether affective stimuli impact eye motor control differently compared to arm and gait control, we administered the EDT and GDT to healthy participants. In the EDT, participants were asked to either make an eye movement toward a peripheral target or refrain from doing so based on whether a centrally presented face showed an emotion or a neutral expression. In the GDT, participants' eye movements were guided by the gender of the face images. According to previous research,[17–19] we hypothesized that if facial emotions automatically attract eye movements regardless of task instructions, participants would make one or more reflexive saccades toward emotional facial features before reaching the target. This behavior would result in similar saccadic reaction times (RTs) and omission error rates (i.e., instances in which participants did not move although they had to) in both the EDT and GDT, as the attentional deployment would be the same across the two tasks. Conversely, if task relevance influences saccades, the valence of facial expressions would affect these behavioral parameters only during the EDT, with threatening faces leading to longer RTs and higher omission error rates. This would indicate that the principles governing the interaction between motor control and emotional stimuli are applicable to all actions performed with the most commonly used effectors.

MATERIALS AND METHODS

Participants

The sample size required to attain a power of 0.80 was predetermined using G*Power 3.1.9.4 software,[20] employing repeated measures analysis of variance (ANOVA) and looking for the within factors (Task*Emotion) effect. We referred to the effect sizes of omission error rates and RTs of reaching arm and gait movements obtained in our previous articles.[5–7,9] We could not consider parameters related to the saccadic amplitude because no prior studies used our design and employed saccadic eye movements. Given that in our previous studies, the effect size ranged from large to very large, we calculated the sample size twice, considering both the lower and upper values of the effect size across all measurements. Thus, the input variables were $\alpha = 0.05$, effect size range $f = 0.39–0.98$, and correlations between repeated measures $r = 0.5$. A minimum sample size of 11–16 people was required. However, since we used a distinct effector (i.e., the eye), we opted to increase the number of participants by 2.5 times with respect to the largest sample. We trusted that by using such a criterion, our power was sufficient to detect all possible effects. Thus, we enrolled 40 students (20 males [mean age ± SD: 23.0 ± 1.6 years] and 20 females [22.4 ± 1.6 years]), from the University of Trieste. We balanced the number of males and females in order to test whether gender differences arise in responding to emotional stimuli in our tasks. Although several investigations have attempted to establish whether there are differences between gender in the ability to recognize basic facial emotion, the results are highly inconsistent.[21,22] Mirabella,[9] exploiting the same experimental paradigm as in this study, found no effect of gender on RTs or omission errors. However, in

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that study, participants were instructed to respond with reaching arm movements rather than saccades. Therefore, we included the factor of Gender in all analyses.

Participants were recruited via advertisements hung in university buildings or published on social media. Recruitment lasted 8 months. Participants did not receive compensation and participated voluntarily. All participants were Caucasian and naive for the purposes of the experiment. They had normal or corrected to normal vision and had no history of neurological or psychiatric disorders. The study was conducted following the ethical guidelines set forth by the Declaration of Helsinki and had the approval from the Ethics Committee of the University of Trieste (number 82/2018). We obtained informed consent from all participants.

Stimuli

We selected pictures of human facial expressions from the Karolinska Directed Emotional Faces database.[23] The faces were taken from 10 different actors, five males, and five females, each with a neutral, happy, or angry expression, resulting in 30 images. We chose to employ angry faces because our two previous studies[15,24] showed that angry faces had a larger effect than fearful faces with the current design. Therefore, since this was our first time using eyes as effectors, we believed it would be more advisable to use the stimulus demonstrating the strongest effect of task relevance.

At the end of the experimental session, we asked participants to evaluate the level of arousal (8-point Likert scale, where 0 meant “not arousing,” and 7 meant “highest arousing”), the valence (15-point Likert scale, where −7 meant “very negative,” 0 meant “neutral,” +7 “very positive”), and recognizability of each picture. The recognizability of emotions was assessed by asking participants to identify emotional faces and, if so, to write down the names of the expressions.

A one-way ANOVA (levels: angry, happy, and neutral faces) on arousal showed that it was higher for angry and happy faces (4.13 $\pm$ 1.33 and 4.37 $\pm$ 1.40, respectively) than neutral expressions (0.99 $\pm$ 1.00, see Table S1 in the Supporting Information). However, the arousal of angry and happy faces did not differ (Table S1). Another one-way ANOVA on the valence of the three facial expressions (levels: angry, happy, and neutral faces) revealed that it differed as expected (anger: −4.65 $\pm$ 1.23; neutral: 0.29 $\pm$ 1.62; happiness: 5.77 $\pm$ 1.03, Table S1). Finally, almost all participants recognized happy (39 out of 40, i.e., 98%), neutral (35 out of 40, i.e., 87%), and angry (40 out of 40, i.e., 100%) expressions.

Apparatus

Eye movements from the right eye were recorded continuously throughout the experiment with a desktop-mounted eye tracker (Eyelink 1000, SR Research Ltd.) at a sampling rate of 500 Hz and a spatial resolution of <0.1° (“°” stands for degrees of visual angle). The eye movement events are generated in real-time during recording based on the default internal heuristic saccade detector that uses a velocity- and acceleration-based saccade detection method (thresholds: 30°/s and 8000°/s^2, respectively). We used a chin rest to minimize head movements and ensure a constant viewing distance of 66 cm. Before starting the experiment, each participant completed a standardized 9-point calibration procedure. The dimensions of the pictures presented at the center of the 21-inch monitor (resolution 1920×1080 pixels) were 215 by 175 pixels, corresponding to 5.28° by 4.30°.

Procedure

The experimental paradigm consisted of two Go/No-go tasks: EDT and GDT. Both tasks were administered in a single session, with a 10-min interval between them to allow for rest. The presentation order of the tasks was counterbalanced across participants.

All trials started with the presentation of a fixation cross at the center of the monitor and remained for 300 ms or until the eye-tracker had detected gaze fixation. If the central fixation was acquired, an open circle (i.e., the target; 250 pixels or 6.14 degrees of diameter) appeared on the right side. After a variable time (300−1000 ms), one picture depicting a facial expression replaced the central fixation point. We carefully aligned the center of the face (i.e., the middle point between the eyes and the nose) with the center of the screen. The face image remained visible until the response.

In the EDT (Figure 1A), participants were instructed to perform one saccade toward the peripheral target appearing on the right side, whenever an emotional face (angry or happy) was presented (Go stimulus). A trial was deemed correct if the saccade successfully landed within a predetermined electronic window, centered around the target with a diameter of 6.14°, and occurred within a maximum time limit of 650 ms. In contrast, participants had to refrain from making a saccade when presenting a neutral face (No-go stimulus) for 650 ms. Written feedback was provided at the end of each response. Twenty pictures (2 genders × 5 persons × 2 emotions) were used as Go stimuli, and 10 pictures (2 genders × 5 persons × 1 neutral expression) as No-go stimuli. Each picture was shown nine times in a random sequence for a total of 270 trials (180 Go trials, frequency: 67%, and 90 No-go trials, frequency: 33%). It should be stressed that in this experimental design, the No-go trials are necessary because, in the EDT, they force subjects to weigh the decision whether to move on every trial and, thus, to use the visual information conveyed by the facial images. In a task where subjects always had to make a saccade to a target, visual information and, thus, the emotional content valence would become irrelevant.

In the GDT (Figure 1B), participants were instructed to perform one saccade toward the peripheral target appearing on the right side whenever a male (or female) face was presented (Go stimulus). A trial was considered correct if the saccade landed within the electronic window (diameter of 6.14°) and occurred within a maximum time of 650 ms. By contrast, they had to withhold the saccadic eye movement for 650 ms when presenting a female (or male) face (No-go stimulus). Written feedback was given at the end of each trial. Twenty participants performed the GDT version, where they had to refrain from moving

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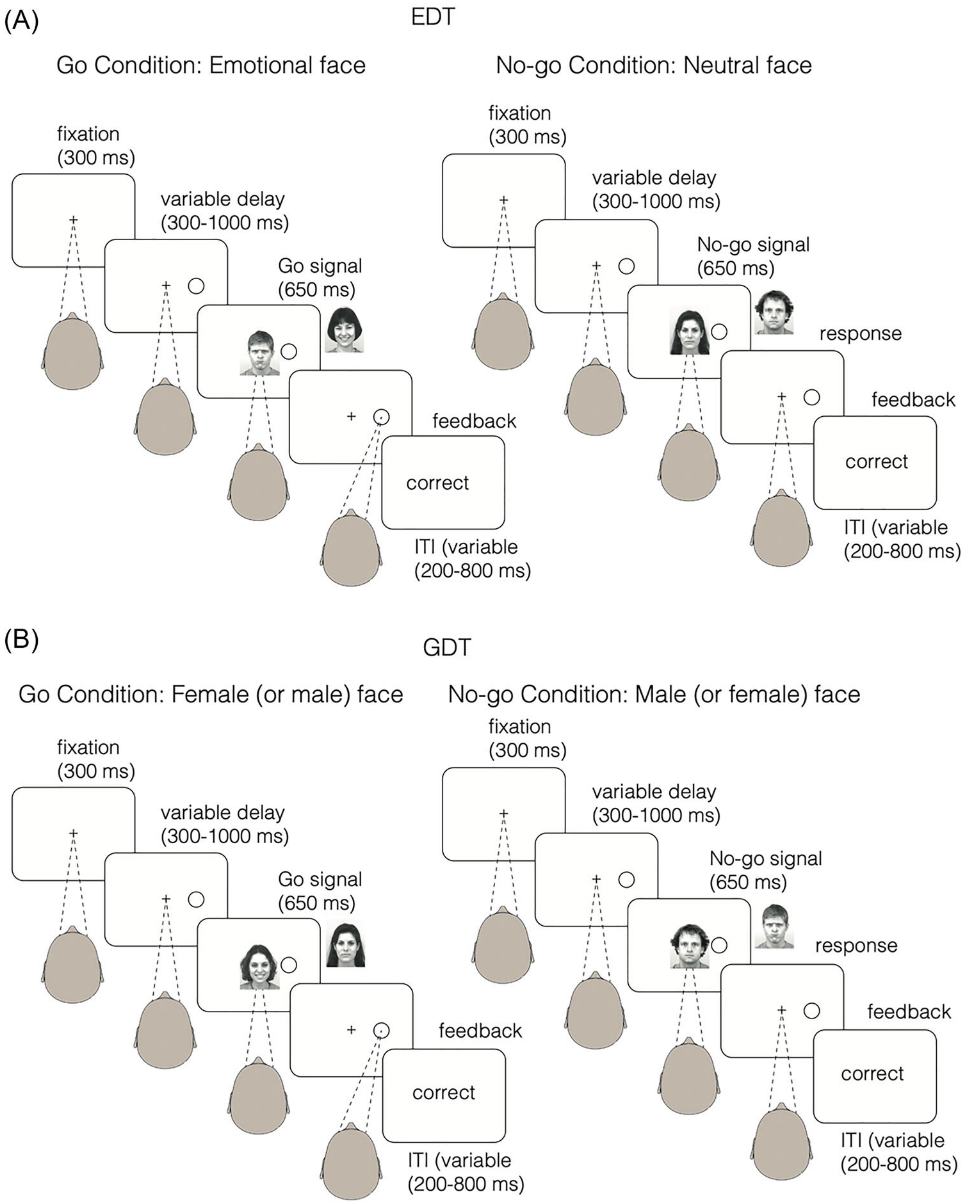

FIGURE 1 Experimental design. (A) Emotional discrimination task (EDT). Each trial started with the appearance of a fixation cross at the center of the screen. Participants were instructed to fixate on it, and just after acquiring fixation, an open circle (the target) appeared on the right side of the screen. After a 300–1000 ms random delay, one picture depicting an angry, happy, or neutral facial expression replaced the central fixation point. Participants had to perform a saccade toward the peripheral target whenever an emotional face (angry or happy) was presented (Go stimulus, 67%). In contrast, they had to refrain from making a saccade when presenting a neutral face (No-go stimulus, 33%). (B) The gender discrimination task (GDT) had the same structure, but participants had to respond or refrain from responding according to the poser's gender. Half of the participants were instructed to respond to the male target and to withhold their response to the female target, and vice versa for the other half. Written feedback was always given at the end of each trial. The dimensions of the face and the circular target do not respect the real proportions of the objects.

to male faces. The other 20 performed the version of the GDT where they had to refrain from moving to female faces. The gender of the posers and that of the participants were balanced. Fifteen pictures (1 gender × 5 persons × 3 emotions) were used as Go stimuli. Each was presented 18 times (270 Go trials, frequency: 67%). The other 15 pictures (1 gender × 5 persons × 3 emotions) were used as No-go stimuli and repeated nine times (135 No-go trials, frequency: 33%). The difference in the total number of trials between the two tasks was necessary to keep the same number of Go stimuli showing angry and happy faces ($n = 90$).

As mentioned earlier, we consistently displayed the target on the right side. This decision was made to allow a comparison of how the task relevance of emotional expressions impacts action readiness across two distinct contexts (EDT vs. GDT), using identical stimuli and movements. If we were to present the target on both the right and left sides, it would have necessitated doubling the number of

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trials, resulting in an excessively lengthy task. In fact, although left-right asymmetries in oculomotor control remain under debate, several works showed the occurrence of spatial asymmetry of saccadic latency, amplitude, and peak velocity.[25–27]

Lastly, but importantly, participants were not informed about the specific emotions they would encounter. Instead, they were instructed to react upon the presentation of facial emotions and to refrain from moving for neutral expressions. Thus, akin to the GDT, each behavior was mapped to one gender; likewise, in the EDT, there was a one-to-one mapping between an emotional expression and a behavioral response.

Data analysis

RTs of correct Go trials and percentage of omission errors were taken as behavioral parameters. RTs were computed as the time difference between the Go stimuli presentation and the saccade onset. In addition, we also decided to analyze the saccadic amplitude, although we did not have any prior expectations. However, in principle, such analyses could disclose whether subjects show a phenomenon that could resemble the idea of approach/avoidance[28] by making saccades of shorter amplitude for angry than for happy faces either in the EDT, GDT, or in both tasks.

The EyeLink Data Viewer Software (SR Research Ltd.) was used to classify the raw eye-movement data in saccades, blinks, and fixations. Saccades were detected according to a combination of velocity (30°/s), amplitude (0.1°), and acceleration (8.000 dva/s^2) thresholds. A missing signal from the pupil lasting more than three samples was used to mark blinks. Blinks were not included in the analysis and constituted a total of 133 instances (42 in the EDT and 91 in the GDT). Any data not classified as saccades or blinks were considered fixations. Examining the distribution of saccade RTs, we observed a small number of outliers (3.3% of the total) represented by saccades with RTs less than 90 ms (Figure S1). These rapid saccades were excluded from our analyses.

In a preliminary analysis of correct saccades in the Go condition, we found that sometimes participants performed two saccades in a single trial within the time limit of 650 ms (9.1% of total trials in the EDT and 6.2% in the GDT). This pattern of saccadic eye movements was found in 34/40 subjects for the EDT and 39/40 subjects for the GDT, with an average frequency of 8.78 ± 9.97 instances in the EDT and 6.21 ± 6.13 instances in the GDT. In these double-saccade trials, the amplitude of the first saccade was very small, and the landing position was always within the face boundaries (exploratory saccades). In the EDT, the landing position focused on the lower part of the face (philtrum-mouth; Figures S2 and S3), whereas in the GDT, the landing position focused on the upper part of the face (nose-eyes; see Figures S2 and S3 of Supporting Information for further details). The second saccade was always directed toward the target (second saccades to the target). We performed four analyses on the saccadic RTs. The first analysis involved trials with only one saccade (EDT, n = 4665; GDT, n = 8159). The other three analyses focused on the two saccades executed in double-saccade trials (EDT, n = 1124; GTD, n = 1254 saccades). In those trials, we considered the RT of the exploratory saccade, the saccade toward the target, and the overall trial RT. The overall trial RT was calculated as the time interval between the presentation of the Go stimuli and the initiation of the second saccade. This encompassed the movement time of the first saccade, in addition to the individual RTs for each saccade. The saccadic amplitude was calculated separately for trials with one saccade (one-saccade trials), exploratory saccades, and second saccades to the target.

All parameters were analyzed with a three-way ANOVA with a mixed design (within-participants factors: Emotion [2 levels: Angry, Happy]; Task [2 levels: EDT, GDT]; between-participants factor: Gender [2 levels: Male, Female]). A Bonferroni correction was used for post hoc comparisons. The effect size measures were reported as partial eta-squared and Cohen's *d*. Statistical analyses were performed using the R programming framework.[29] In particular, the ANOVA and post-hoc tests were performed with the *jmv* package.[30] We also computed the Bayes Factor (BF_{10}),[31] setting the prior odds to 0.707 to quantify the null and alternative hypotheses' strength (R package BayesFactor).[32] (a) BF_{10}>3 and BF_{10}>10 give substantial and strong support for the alternative hypothesis, respectively; (b) BF_{10}<0.10 and BF_{10}<0.33 provide strong and substantial support for the null hypothesis, respectively; and (c) 0.33< BF_{10}< 3 can be regarded inconsistent for any hypothesis.

RESULTS

Table 1 summarizes the mean values of behavioral and kinematic parameters of interest.

Impact of task relevance on saccadic RTs

First, we present the results pertaining to trials involving a single saccade followed by the findings related to trials in which two saccades were executed consecutively.

One-saccade trials

The ANOVA on mean RTs revealed a statistically significant main effect of Task, Emotions, and their interaction (Table 2). The main effect of the Task showed that participants had shorter RTs in the GDT than in the EDT (342.10 ± 30.96 vs. 365.04 ± 30.14 ms). The main effect of Emotion was due to longer RTs after the presentation of angry compared to happy faces (357.48 ± 26.65 ms vs. 349.65 ± 27.12 ms). These effects are qualified by the interaction between the two factors. Angry faces elicited longer RTs than happy faces only in the EDT. On the other hand, there was no difference between the two facial expressions in the GDT (Table 2 and Figure 2). Bayesian analysis strongly supported the existence of a significant difference between angry and happy expressions in the EDT (Table 2), while it almost supported the absence of such a difference in the GDT (Table 2).

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TABLE 1 Means and standard deviations of behavioral and kinematic parameters of Go trials.

	EDT		GDT	
	Angry	Happy	Angry	Happy
One-saccade trials				
RT saccades to the target (ms)	371.84 ± 32.87	358.24 ± 28.99	343.12 ± 30.88	341.07 ± 31.90
Saccade amplitude (°)	5.73 ± 0.68	5.70 ± 0.70	5.77 ± 0.82	5.73 ± 0.85
Double-saccade trials				
RT exploratory saccades (ms)	252.34 ± 47.59	235.90 ± 30.20	228.50 ± 30.11	228.29 ± 29.17
Saccade amplitude (°)	0.51 ± 0.14	0.49 ± 0.14	0.58 ± 0.26	0.55 ± 0.18
RT second saccades to target (ms)	156.48 ± 29.44	155.73 ± 21.42	152.03 ± 23.61	151.87 ± 22.49
Saccade amplitude (°)	5.81 ± 0.61	5.88 ± 0.65	5.81 ± 0.75	5.93 ± 0.92
RT of double-saccades (ms)	415.33 ± 42.69	396.66 ± 34.73	384.87 ± 35.75	389.43 ± 24.24
All trials				
Omission errors (%)	24.92 ± 9.55	14.67 ± 7.59	10.25 ± 8.70	10.72 ± 9.23

Note: ° indicates degrees of visual angle.
RT, reaction time.

Double-saccade trials

The ANOVA on mean RTs of both the exploratory saccades and the second saccades to the target revealed no statistically significant effects (Table 2) either in the EDT or GDT.

In contrast, the ANOVA conducted on the mean RTs of the double-saccades showed a statistically significant main effect of Task (Table 2). This was because participants had shorter RTs in the GDT than EDT (387.15 ± 25.07 vs. 406.00 ± 35.58 ms). The interaction between Task and Emotion stemmed from angry faces leading to longer RTs than happy faces in the EDT (Table 2). Conversely, no such differences were observed in the GDT (Table 2 and Figure 2). Bayesian analysis substantially supported the existence of a significant difference between angry and happy expressions in the EDT and the absence of such a difference in the GDT (Table 2).

To assess whether angry and happy faces elicited RTs of different lengths with respect to neutral faces, we compared the mean RTs among these conditions in the GDT via a two-way ANOVA with a mixed design (within factor: Emotion [Happy, Anger, and Neutral]; between factor: Gender of participants [Male, Female]). We did not find any significant difference between angry (trials with one saccade: 343.11 ± 30.88 ms; double-saccade trials, double-saccades: 384.87 ± 35.75 ms), happy (trials with one saccade: 341.07 ± 31.90 ms; double-saccade trials, double-saccades: 389.43 ± 24.24 ms), and neutral faces (trials with one saccade: 340.21 ± 30.71 ms; double-saccade trials, double-saccades: 391.53 ± 43.41 ms; Table 3 and Figure 3).

Impact of task relevance on omission errors

The ANOVA on the omission errors showed a statistically significant main effect of Task, Emotions, and their interaction (Table 4). For the main effect of Task, participants had a higher percentage of omission errors in the EDT than in the GDT (19.79 ± 7.17% vs. 10.49 ± 8.65%). The main effect of Emotion showed that participants made more omission errors for angry than happy faces (17.58 ± 7.35% vs. 12.69 ± 7.54%). Their interaction qualifies both main effects. In the EDT, the rate of omission errors for angry faces was higher than for happy faces, while in the GDT, there was no difference (Table 4 and Figure 2). Bayesian analysis provided strong support for a significant difference between angry and happy expressions in the EDT, whereas it indicated the absence of such a difference in the GDT (Table 4).

Once more, to compare the mean omission error rates across neutral, angry, and happy faces, we employed a two-way ANOVA with a mixed design (within factor: Emotion [Happy, Anger, and Neutral]; between factor: Gender of participants [Male, Female]), focusing on the values obtained in the GTD. We found no statistically significant difference among angry (10.25 ± 8.70%), happy (10.71 ± 9.23%;), and neutral faces (10.75 ± 7.95%; Table 4 and Figure 2).

Impact of task relevance on saccade amplitude

First, we checked whether the amplitude of the three saccade categories (one-saccades, exploratory saccades, and second saccades to target) had different amplitudes. As shown in Figure 2, we found that, regardless of the task, the amplitude of the exploratory saccades was smaller than 1° (see Table 1), and thus, they can be classified as microsaccades.[33,34] The ANOVA on one-saccade and second saccades to target yielded no significant effects (Table 5), and Bayesian factors provided strong support for the null hypotheses. Instead, the ANOVA on the exploratory saccades revealed a significant main effect for Gender as the exploratory saccades of males had amplitudes slightly smaller than females (0.48 ± 0.18° vs. 0.59 ± 0.17°). However, such an effect was negligible as Bayesian factors were inconsistent with any hypotheses.

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TABLE 2 Results of the statistical analyses on saccadic reaction times of Go trials.

	Effect	Factors	df	Statistics	p-value	E.S.	BF_{10}
One-saccade trials							
RT	Main	Task	(1,38)	**F=23.17**	**<0.0001**	**0.38**	**>100**
	Main	Emotion	(1,38)	**F=36.64**	**<0.0001**	**0.49**	**3.05**
	Main	Gender	(1,38)	F=0.10	0.753	0.00	0.27
	Interaction	Task * Emotion	(1,38)	**F=14.67**	**<0.0001**	**0.28**	**2.00**
	Interaction	Task * Gender	(1,38)	F=0.63	0.431	0.02	0.35
	Interaction	Emotion * Gender	(1,38)	F=0.91	0.346	0.02	0.19
	Interaction	Task * Emotion * Gender	(1,38)	F=0.38	0.543	0.01	0.08
	Post hoc comparison	EDT: Anger versus Happy	(38)	**t=5.95**	**<0.0001**	**0.94**	**>100**
	Post hoc comparison	GDT: Anger versus Happy	(38)	t=1.25	0.435	0.20	0.36
Double-saccade trials							
RT (exploratory saccades)	Main	Task	(1,21)	F=3.79	0.065	0.15	2.01
	Main	Emotion	(1,21)	F=2.78	0.110	0.12	0.32
	Main	Gender	(1,21)	F=1.75	0.200	0.08	0.35
	Interaction	Task * Emotion	(1,21)	F=3.24	0.086	0.13	0.44
	Interaction	Task * Gender	(1,21)	F=0.15	0.698	0.01	0.30
	Interaction	Emotion * Gender	(1,21)	F=1.42	0.246	0.06	0.21
	Interaction	Task * Emotion * Gender	(1,21)	F=0.47	0.499	0.02	0.05
RT (second saccades to target)	Main	Task	(1,21)	F=0.52	0.477	0.02	0.13
	Main	Emotion	(1,21)	F=0.01	0.926	0.00	0.09
	Main	Gender	(1,21)	F=0.20	0.657	0.01	0.13
	Interaction	Task * Emotion	(1,21)	F=0.01	0.943	0.00	0.03
	Interaction	Task * Gender	(1,21)	F=0.29	0.593	0.01	0.05
	Interaction	Emotion * Gender	(1,21)	F=0.36	0.557	0.02	0.04
	Interaction	Task * Emotion * Gender	(1,21)	F=0.37	0.552	0.02	0.00
RT (double-saccades)	Main	Task	(1,21)	**F=6.23**	**0.021**	**0.23**	**10.74**
	Main	Emotion	(1,21)	F=1.62	0.217	0.07	0.44
	Main	Gender	(1,21)	F=3.13	0.09	0.13	0.58
	Interaction	Task * Emotion	(1,21)	**F=7.78**	**0.011**	**0.27**	**1.09**
	Interaction	Task * Gender	(1,21)	F=0.04	0.841	0.00	0.41
	Interaction	Emotion * Gender	(1,21)	F=0.00	0.973	0.00	0.22
	Interaction	Task * Emotion * Gender	(1,21)	F=0.41	0.528	0.02	0.08
	Post hoc comparison	EDT: Anger versus Happy	(21)	**t=2.84**	**0.020**	**0.61**	**5.95**
	Post hoc comparison	GDT: Anger versus Happy	(21)	t=−0.62	1.000	0.14	0.27

Note: The statistics, *p*-value, E.S., and BF_{10} of statistically significant results (i.e., $p < 0.05$) are shown in bold. Abbreviations: BF_{10}, Bayes Factor; df, degrees of freedom; E.S., effect size (partial eta squared for ANOVAs and Cohen's *d* for post hoc tests); RT, reaction time.

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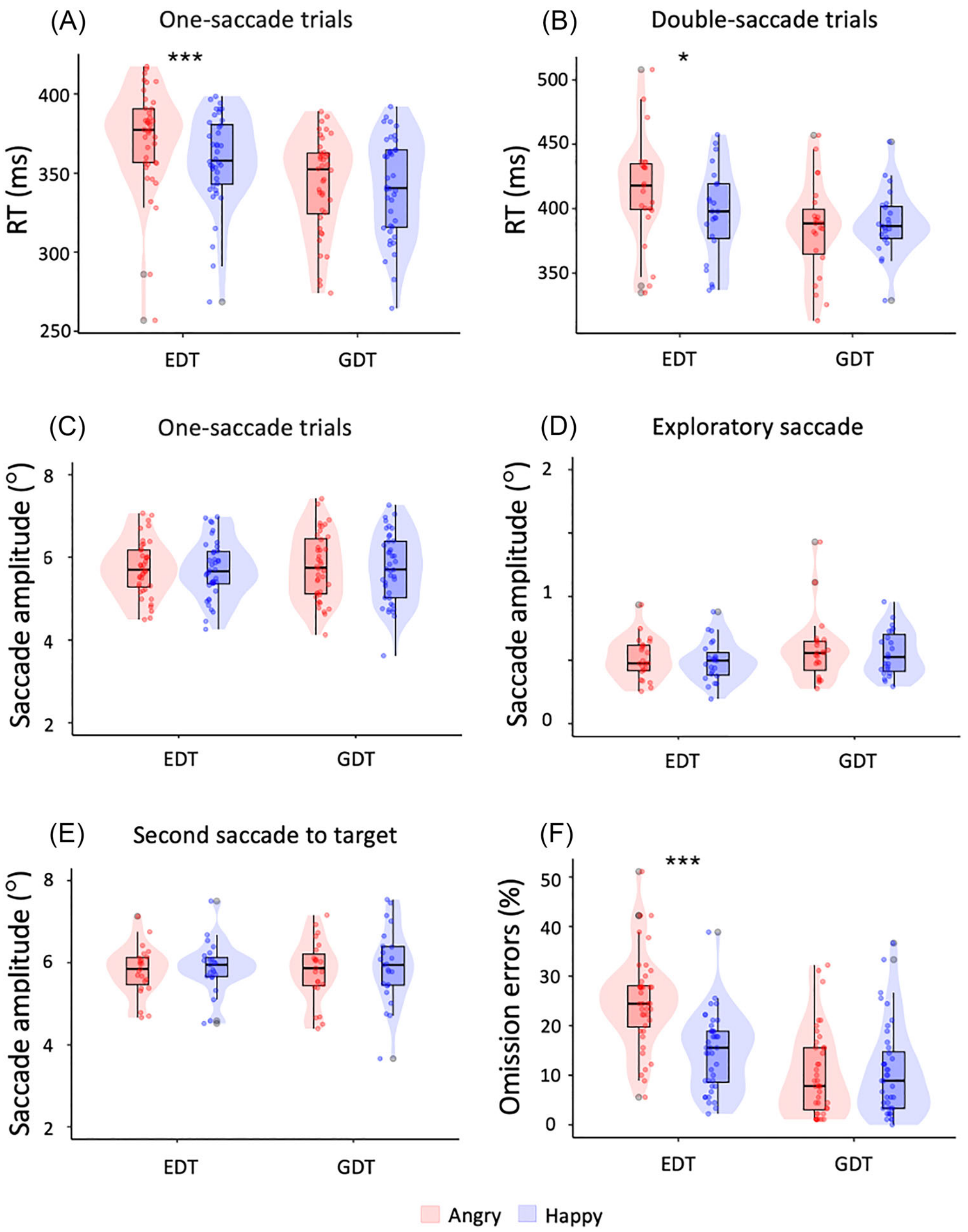

FIGURE 2 Effect of valence of emotional facial expressions on reaction times (RTs, A and B), saccade amplitude (C, D, E), and rate of omission errors (F) in the EDT (left) and GDT (right). Participants in the EDT were slower and less accurate when the Go-signal was an angry face rather than a happy face. However, no difference occurred in the GDT. Saccadic amplitude never differed in the EDT or GDT. One-saccade trials were trials where only one saccade was performed. Double-saccade trials were trials where two saccades were performed (see text for details). ° indicates degrees of visual angle. *p<0.05; ***p<0.001.

Commission errors in No-go trials

For completeness, we also computed the accuracy of the No-go trials in the EDT (commission errors: 28.61 ± 17.11%) and in the GDT (commission errors: 12.00 ± 8.84%). Notably, in the EDT, the No-go signal was always for neutral facial expressions, whereas in the GDT, the no-Go signal could be either a neutral, happy, or angry expression. Thus, first, using a one-way ANOVA (3 levels: Happy, Anger, and Neutral), we checked whether the rate of commission errors in the GDT differed as a function of the facial expression. We found no statistically significant differences between expressions ($F(1.66, 63.03) = 1.81$, $p = 0.177$; $\eta_p^2 = 0.05$, $BF_{10} = 0.26$). Second, we compared the overall rates of commission errors in the EDT versus GDT using a paired t-test. We found that the participants made a significantly higher rate of commission errors in the EDT than GDT ($t(39) = 7.25$, $p < 0.001$; Cohen's $d = 1.15$, BF_{10}>100), reflecting the fact that the former task is more difficult than the latter.

DISCUSSION

Our previous research showed that the valence of emotional stimuli impacts gait or arm movements only when they are relevant to a participant's goals.[4–9] However, when using the eyes as effectors,

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TABLE 3 Results of the statistical analyses on reaction times in the GDT.

	Effect	Factors	df	Statistics	*p*-value	E.S.	BF_{10}
One-saccade trials							
RT	Main	Emotion	(2,76)	F=1.94	0.150	0.05	0.28
	Main	Gender	(1,38)	F=0.01	0.903	0.00	0.50
	Interaction	Emotion * Gender	(2,76)	F=0.02	0.977	0.00	0.07
Double-saccade trials							
RT	Main	Emotion	(2,42)	F=0.41	0.664	0.02	0.13
	Main	Gender	(1,21)	F=1.36	0.257	0.06	0.46
	Interaction	Emotion * Gender	(2,42)	F=1.03	0.367	0.05	0.09

Abbreviations: BF_{10}, Bayes Factor; df, degrees of freedom; E.S., effect size (partial eta squared for ANOVAs and Cohen's *d* for post hoc tests); RT, reaction time.

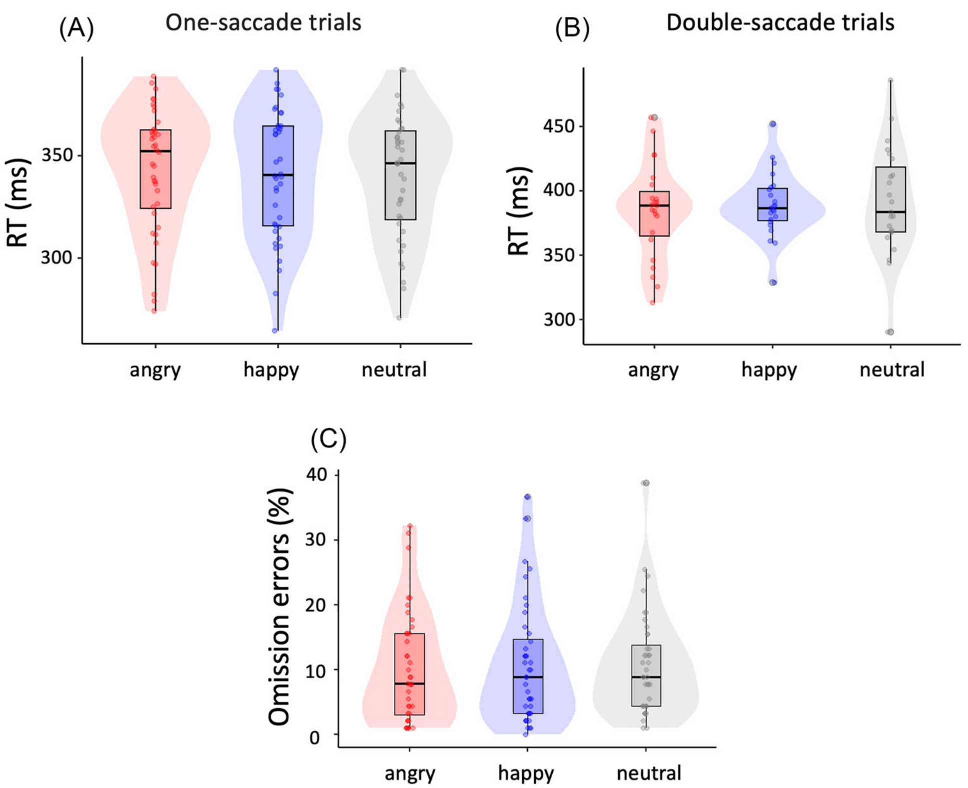

FIGURE 3 Effect of valence of emotional facial expressions on reaction times (RTs, A and B) and the rate of omission errors (C) in the GDT. No significant difference between angry, happy, and neutral expressions occurred. One-saccade trials were trials where only one saccade was performed. Double-saccade trials were trials where two saccades were performed (see text for details).

such an effect is not assured as it has been suggested that emotional facial expressions automatically bring the gaze toward facial regions that are crucial for categorizing emotions.[17–19] If this were the case, the task-relevance phenomenon would vanish because the attentional deployment would be the same in both tasks. Thus, we tested whether the relevance of facial expressions impacts eye motor control. We found that participants showed two different patterns of saccadic eye movements. The most prevalent behavior, on average about 93% of the time, consisted of performing one saccade from the fixation point to the peripheral target. In approximately 7% of instances, participants performed two saccades. The first saccade was quick and directed toward context-specific diagnostic features of the poser's face, which differed according to the task at play, that is, distinguishing between a neutral and an emotional face in the EDT and distinguishing between a man and a woman in the GDT (see below for further discussion and see the Supporting Information). The second saccade was directed to the target. In both cases, we found that the valence of facial emotional expressions affected the saccadic RTs and the rate of omission errors,

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TABLE 4 Results of the statistical analyses on the rate of omission errors.

	Effect	Factors	df	Statistics	*p*-value	E.S.	BF_{10}
EDT and GDT							
Omission errors	Main	Task	(1,38)	**F=55.87**	**<0.0001**	**0.59**	**>100**
	Main	Emotion	(1,38)	**F=30.46**	**<0.0001**	**0.44**	**>100**
	Main	Gender	(1,38)	*F*=1.01	0.321	0.03	0.29
	Interaction	Task * Emotion	(1,38)	**F=44.70**	**<0.0001**	**0.54**	**>100**
	Interaction	Task * Gender	(1,38)	*F*=0.01	0.930	0.00	0.27
	Interaction	Emotion * Gender	(1,38)	*F*=0.22	0.642	0.01	0.23
	Interaction	Task * Emotion * Gender	(1,38)	*F*=0.12	0.730	0.00	0.09
	Post hoc comparison	EDT: Anger versus Happy	(38)	**t=6.76**	**<0.0001**	**1.08**	**>100**
	Post hoc comparison	GDT: Anger versus Happy	(38)	*t*=−0.63	1.000	0.10	0.21
GDT (with neutral stimuli)							
Omission errors	Main	Emotion	(2,76)	*F*=0.33	0.717	0.01	0.07
	Main	Gender	(1,38)	*F*=0.41	0.527	0.01	0.42
	Interaction	Emotion * Gender	(2,76)	*F*=0.58	0.564	0.01	0.03

Note: Note: The statistics, *p*-value, E.S., and BF_{10} of statistically significant results (i.e., $p < 0.05$) are shown in bold.
Abbreviations: BF_{10}, Bayes Factor; df, degrees of freedom; E.S., effect size (partial eta squared for ANOVAs and Cohen's *d* for post hoc tests) RT, reaction time.

but only in the EDT (i.e., when the emotional content of the stimuli was relevant for giving a response). Such results indicate that motor reactions to emotional stimuli obey the same principles in spite of the effectors being employed to respond.

We believe that our evidence is solid for several reasons. First, we adopted a within-subject design where all participants performed the EDT and the GDT in a counterbalanced order. Second, we compared the impact of the same images when task-relevant versus irrelevant. Third, the arousal cannot explain the results as the chosen emotional stimuli did not differ under this dimension. Fourth, all statistically significant results had robust effect sizes. Fifth, Bayesian factors substantially supported (a) the differences between angry and happy faces for both omission errors and RTs in the EDT and (b) the absence of such differences in the GDT.

Task relevance impacts saccadic motor control

The analyses of RTs and omission error rates indicated that angry faces slow down saccadic movements and decrease their accuracy with respect to happy faces but solely in the EDT. No statistical differences occurred in the GDT. Such results confirm and expand previous findings obtained using the same experimental design either when the effector was the arm[4,5,7–9] or the legs.[6] In all these instances, the valence of emotional expressions affected movement execution only when participants were explicitly instructed to respond[6,7,9,15] or to refrain from responding[4,8] according to the fact that the posers showed an emotion. When the emotional content of the stimuli was task-irrelevant, it never affected motor control. When task-relevant, the face's valence always had the same impact (i.e., threatening faces slowed down the RTs and increased the rates of mistakes more than happy faces). In our previous work, we suggested that these effects might occur because threatening expressions delay attentional disengagement, prompting individuals to monitor potential threats more closely.[5,6,9,15] Fox et al. reached similar conclusions using a different paradigm.[35,36] However, manual and gait responses are an indirect index of attention. Instead, saccades have a much more proximal relation to attention.[37,38] In this study, we presented the facial stimuli at fixation, and thus before performing the saccades, participants had to shift their attention to the target location covertly.[39,40] Therefore, the increased saccadic latency indicates a more demanding process of attentional disengagement. Such lengthening could further explain the higher rate of omission errors, given that we imposed a time limit for saccade execution in Go trials. Given that the results on saccades align with those on arms and legs, we suggest that in the EDT, angry faces hold attention more strongly than happy faces because participants tend to evaluate whether such expressions represent a real menace. This is not a bottom-up but a top-down effect because attentional holding occurs only when emotional faces are contingent on goal relevance. In fact, in the GDT, angry faces do not hold attention more than other expressions. The same logic applies whether participants execute one saccade to reach the target or two (see below for a detailed discussion of these instances).

Interestingly, Belopolsky et al.[41] showed that a delayed disengagement of attention from angry faces with respect to happy and neutral expressions occurred even when those stimuli were task-irrelevant. This discrepancy can be explained by differences in the experimental design, mainly that Belopolsky et al.[41] used a schematic instead of real faces. Evidence suggests that the process of face

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TABLE 5 Results of the statistical analyses on the saccadic amplitude.

	Effect	Factors	df	Statistics	*p*-value	E.S.	BF_{10}
One-saccade trials							
Amplitude	Main	Task	(1,38)	*F*=0.36	0.554	0.01	0.12
	Main	Emotion	(1,38)	*F*=2.90	0.096	0.07	0.13
	Main	Gender	(1,38)	*F*=0.04	0.841	0.00	0.23
	Interaction	Task * Emotion	(1,38)	*F*=0.26	0.613	0.01	0.03
	Interaction	Task * Gender	(1,38)	*F*=0.07	0.786	0.00	0.04
	Interaction	Emotion * Gender	(1,38)	*F*=0.00	0.996	0.00	0.05
	Interaction	Task * Emotion * Gender	(1,38)	*F*=0.32	0.575	0.01	0.00
Double-saccade trials							
Amplitude (exploratory saccades)	Main	Task	(1,21)	*F*=2.74	0.112	0.12	0.73
	Main	Emotion	(1,21)	*F*=0.81	0.380	0.04	0.15
	Main	Gender	(1,21)	***F*=4.54**	**0.045**	**0.18**	**0.93**
	Interaction	Task * Emotion	(1,21)	*F*=0.00	0.971	0.00	0.12
	Interaction	Task * Gender	(1,21)	*F*=2.00	0.172	0.09	0.82
	Interaction	Emotion * Gender	(1,21)	*F*=0.31	0.583	0.01	0.14
	Interaction	Task * Emotion * Gender	(1,21)	*F*=0.07	0.790	0.00	0.03
Amplitude (second saccades to target)	Main	Task	(1,21)	*F*=0.04	0.850	0.00	0.11
	Main	Emotion	(1,21)	*F*=2.45	0.132	0.10	0.16
	Main	Gender	(1,21)	*F*=1.18	0.289	0.05	0.29
	Interaction	Task * Emotion	(1,21)	*F*=0.10	0.751	0.01	0.04
	Interaction	Task * Gender	(1,21)	*F*=0.65	0.429	0.03	0.10
	Interaction	Emotion * Gender	(1,21)	*F*=0.20	0.657	0.01	0.08
	Interaction	Task * Emotion * Gender	(1,21)	*F*=0.51	0.484	0.02	0.01

Note: The statistics, *p*-value, E.S., and BF_{10} of statistically significant results (i.e., $p < 0.05$) are shown in bold.
Abbreviations: BF_{10}, Bayes Factor; df, degrees of freedom; RT, reaction time.

recognition varies, with real faces being recognized through a holistic approach that combines features into a unified whole, whereas schematic faces are identified through a feature-based approach, relying on individual features like the eyes or mouth.[42] In addition, the results of Belopolsky et al.[41] should be interpreted cautiously as (a) the sample size was small ($n = 18$), (b) the effect sizes are not reported, and (c) the Bayes Factors were not computed.

On the other hand, this is not the first time that it has been shown that task-irrelevant facial expressions do not affect saccadic oculomotor control. Using a visual search task, Hunt et al.[14] compared the ability of schematic angry and happy distractor faces to attract the eyes. They found that both distractor faces interfered with the search because they increased the saccadic RT toward the target and decreased the accuracy when the distractors were not present. However, there were no differences according to the emotion displayed by the distractors. Therefore, they concluded that, unlike hypotheses by other studies (e.g., Ref. 43), attention is not automatically and preferentially allocated to threatening stimuli. Devue and Grimshaw[13] confirmed and expanded these findings a few years later using pictures of real faces. They presented healthy participants with a circular array of six circles placed around the central fixation point and instructed them to make a saccade toward the circle with a unique color. In each trial, a separate circular array of photos depicting objects and angry or neutral faces was shown within the first one (i.e., nearer to the fixation point). Participants had to ignore them and focus on the target stimulus. Notably, only one face was shown in the array of distractors at a time. As the authors previously showed, facial images can drive saccades in a bottom-up fashion.[44] With this novel design, they aimed to assess whether facial emotions could be automatically prioritized when competing for attention with the target stimulus. They found that angry and neutral faces reflexively drew participants' gaze and attention on a small portion of trials. However, angry expressions have an effect comparable to that of neutral faces. On this basis, Devue and Grimshaw[13] concluded that faces can attract attention automatically because of their social relevance, but emotional expressions do not increase automatic attentional capture.

Our results confirm those obtained by the two above-cited studies, contrasting other evidence.[17–19,41] However, our data provide a more robust demonstration of the task-relevance phenomenon because our design allowed us to maximally challenge the attentional system. In fact, we presented faces within the participant's focus of attention, asking them to respond according to different facial features (those allowing the detection of an emotional expression in the EDT and the gender in the GDT). Thus, we showed that the same person can modulate his/her attention to respond according to the task instructions.

The double-saccades

Although participants successfully maintained well-controlled oculomotor behavior in most trials, there were a few instances, less than 8%, in which some facial features captured the eyes reflexively, and participants had to execute a second saccade to the target. These rare events are worthy of discussion because other authors have found similar phenomena.[13,17–19] Notably, we showed that, at least in this setting, the exploratory saccades are microsaccades.[33,34,45] The role of such eye movements is debated. Studies have established a link between microsaccades and cognitive functions, especially in relation to attention allocation.[33,34,45] In this regard, we found that the landing positions of microsaccades changed with the task. During the EDT, these saccades targeted the lower facial region, specifically the mouth area, which holds critical elements for discerning emotional expressions.[46–48] Conversely, in the GDT, they were aimed at the upper face, mainly focusing on the nose and eyes regions, which are pivotal for distinguishing between male and female faces (see Supporting Information). Nevertheless, no significant differences in behavioral parameters between exploratory saccades toward happy or angry faces in the EDT and GDT occurred. The meaning of those saccades is unclear, but we believe that the most likely explanation is that they represent instances of decreased participant's oculomotor control during which relevant features of the facial expression automatically capture attention.

As described above, Devue and Grimshaw[13] showed that in about 13% of instances, task-irrelevant faces elicited automatic saccades with RTs close to those recorded in our experiment. They interpreted them as occasions where biologically salient stimuli could deceive oculomotor control because of spontaneous fluctuations in attention.[49] Bodenschatz et al.[18] also showed the occurrence of automatic saccades toward different regions of neutral faces after showing emotional faces as prime stimuli. Although emotional faces were irrelevant to the task and were not consciously perceived by participants, they found that the scanning of the neutral faces differed according to the previously presented prime. After a happy expression, participants moved their gaze quickest and dwelled longest on the mouth region of the neutral face, while after a fearful face, they made the fastest saccades and dwelled longest on the eye region of the neutral face. In spite of the fact that Bodenschatz et al.[18] claimed that such saccades play a role in the perception of facial emotions, they did not find a behavioral effect of the affective priming, that is, there was no correlation between the emotional prime stimuli, the gaze behavior, and the evaluation of the neutral face valence. Similarly, Gamer and Buchel[19] and Scheller et al.[17] showed that participants automatically processed facial features that are diagnostic for emotion processing irrespective of the task and the position in the visual field where the facial expression was shown. However, they did not report any benefit of those gaze patterns on behavioral choices. Notably, the percentages of saccades in Gamer and Buchel[19] and Scheller et al.[17] are much higher than in Devue and Grimshaw[13] and our study. Such a difference could be due to the fact that the former studies explicitly asked for the recognition of a facial expression, while the latter two did not. Further studies are needed to clarify the role of the exploratory saccades.

From our perspective, the pivotal aspect of the double saccades lies in the reappearance of the task-relevance effect when examining the RTs encompassing the entire trial. We chose to compute the RT in the whole sequence of events, beginning with the first fixation, proceeding through the movement phase, and concluding with the second fixation before landing on the target. This approach is driven by the likelihood that task instructions influence each of these phases, extending beyond transitory lapses in oculomotor control.

No evidence of an impact of participants' gender on behavioral performance

Consistent with Mirabella's[9] findings, we did not find a significant main effect of Gender or an interaction including Gender, except for the saccadic amplitude of the exploratory saccades. The observed effect was minimal, as indicated by the Bayes Factor, and additional research is necessary to investigate it further. To summarize, we find no difference in how males and females react to facial emotions.

Limitations

The main limitation of the current study stems from the poor ecological validity of static and out-of-context face images. We cannot entirely exclude that the salience of such stimuli is not great enough to generate a bottom-up attentional bias that might instead be present in real-world situations. This challenge could be addressed by leveraging innovative experimental setups using virtual reality. Developing virtual environments and contexts closely mirroring reality might serve as a litmus test to validate our findings.

CONCLUSIONS

Our study revealed that the valence of facial emotional expressions influences saccadic behavior, and hence attention, only when it is relevant to participants' goals. These findings provide strong support for the idea that emotion processing is a dynamic and multicomponent

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process in which stimulus evaluation is a crucial component. According to this view, the valence of a stimulus does not automatically induce a reaction in the observer, but it is weighted based on the context in which he/she operates. As a result, participants interpret the emotional valence of the same angry face very differently in the EDT and GDT, leading to longer RTs and higher omission error rates exclusively in the EDT. Moreover, this evidence suggests that the interaction between emotional stimuli and motor responses is governed by the same principles regardless of the effectors utilized.

AUTHOR CONTRIBUTIONS

G.M. and P.B., conceptualization; P.B., methodology and data collection; M.G., data analyses; G.M., writing of the original draft; P.B., G.M., and M.G., writing, review, and editing; G.M., funding acquisition; G.M. and P.B., supervision. All authors approved the final version of the manuscript for submission.

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COMPETING INTERESTS

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repositories and accession numbers can be found at: https://osf.io/t7adu/

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