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Emotion-specific Sensitivity in an unconscious Facial Perception Task

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ABSTRACT

Emotions are crucial in social interactions, influencing communication and relationships. Distinguishing the perceived emotion in conscious and unconscious emotional processing is a key research area with cognitive and physiological implications. This study investigates conscious and unconscious emotional processing through behavioral and pupillary responses. Participants completed emotion recognition tasks under varying states, revealing higher accuracy in conscious emotion identification. Emotions like anger, happiness, fear, surprise, and neutral elicited distinct response patterns. Pupillometry data showed pupil size suppression in the conscious state and enhancement in the unconscious state, with differences in peak pupil size across emotions. Task-related components, amplitude, and latency parameters differed between conscious and unconscious states, highlighting the role of awareness in emotional regulation. These findings emphasize the complex interplay of cognitive and physiological processes in emotional responses, providing insights into emotional recognition mechanisms. This study contributes to understanding emotional processing dynamics and has implications for psychology and neuroscience research.

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Introduction

Emotions have evolved to fulfill our need for fast and efficient communication, playing a pivotal role in human social interactions. Through facial expressions, people convey critical information about their thoughts and feelings, and the ability to interpret these cues is essential for effective interpersonal communication. This makes facial affect recognition a fundamental skill for understanding others' emotions and fostering positive social relationships (Spikman et al., 2013).

Like other cognitive processes, emotional processing can be divided into conscious and unconscious mechanisms (Kihlstrom et al., 2000). These two modes of processing differ qualitatively and quantitatively, engaging distinct neural pathways: unconscious processing primarily involves evolutionarily older subcortical structures (e.g., the amygdala), while conscious processing recruits cortical regions (Phillips et al., 2004; Tamietto et al., 2015). Neuroimaging studies show amygdala activation in response to masked emotional faces, even when individuals report no awareness of the stimuli (Tamietto & de Gelder, 2010). This suggests that subcortical pathways mediate rapid, automatic emotional responses, which may indirectly influence cortical activity. Tamietto and de Gelder (2010) propose that conscious and unconscious emotional processing are not entirely segregated. Instead, they involve dynamic interactions between cortical and subcortical pathways. Conscious perception engages cortical regions, which may suppress subcortical activity via inhibitory feedback—a phenomenon that could explain why subcortically driven responses (e.g., pupil dilation or facial mimicry) are paradoxically stronger during unconscious perception. For example, individuals with affective blindsight (a condition where cortically blind individuals retain unconscious emotional responsiveness) and healthy controls show heightened facial muscle activity in response to subliminal emotional stimuli compared to consciously perceived ones (Celeghin et al., 2015; Tamietto et al., 2009; Dimberg et al., 2000). Such findings highlight that emotional recognition can occur automatically, bypassing conscious awareness.

To investigate these processes, pupillometry has emerged as a powerful tool for measuring autonomic arousal linked to emotional and cognitive states. Since Hess and Polt's (1960) seminal work linking pupil dilation to emotional valence, researchers have used pupillometry to study both conscious and unconscious processing (Wang et al., 2018). Pupil size fluctuations (≈0.5 mm) reflect sympathetic activation of the locus coeruleus a brainstem nucleus regulating arousal and are sensitive to cognitive load, attention, and emotional intensity (Laeng, 2012). Critically, pupillometry captures subcortically mediated responses, making it a "window to the preconscious" (Laeng, 2012). For example, adults exhibit greater pupil dilation to masked fearful faces than neutral ones, even without conscious recognition (Laeng, 2012). Notably, these autonomic responses are diminished in populations with social deficits, such as autism, underscoring their relevance to real-world social functioning (Nuske, 2014). However, while prior work has focused on fear and happiness, the distinct pupillary responses to other basic emotions such as disgust or surprise remain unexplored, particularly in unconscious perception.

Another key aspect of emotional processing is the recognition threshold the minimum exposure time required to identify an emotion. Studies reveal systematic differences in these thresholds across emotions and populations. For instance, happiness is recognized most accurately across age groups, whereas fear recognition declines with aging (Calder et al., 2003). Subliminally, fearful faces are detected at shorter durations (10–25 ms) compared to happy or neutral faces, which require longer exposures (Tsikandilakis et al., 2021). These thresholds also vary by gender and culture, though accuracy is not strongly tied to ethnic background. Despite these advances, how recognition thresholds interact with autonomic responses like pupil dilation especially in conscious versus unconscious states remains unclear.

While prior work has often focused on fear and happiness, the distinct pupillary responses to other basic emotions such as disgust or surprise remain less explored in unconscious perception, particularly using pupillometry (Duan et al., 2010). Furthermore, the dynamics of emotions like sadness and anger across conscious states are not fully understood.

To address this gap, our study investigates how different basic emotions (happiness, sadness, anger, fear, surprise, disgust) affect pupil size during conscious and unconscious perception. Twenty-eight healthy participants completed a computerized task with masked and unmasked facial expressions while pupil size was tracked via eye-tracking. We hypothesize that: Recognition accuracy will vary across emotions, with happiness identified most reliably. Distinct pupil dilation patterns will emerge for different emotions, with fear eliciting the strongest response. Pupil dilation will be greater for unconsciously perceived stimuli due to cortical suppression of subcortical pathways during conscious processing.

By integrating pupillometry with emotion recognition thresholds, this study advances our understanding of the neural and autonomic dynamics underlying conscious and unconscious emotional processing. These findings could inform models of social functioning in clinical populations, such as autism or affective blind sight, where disrupted emotional processing contributes to social deficits.

Method

Participants

Twenty-eight healthy participants (12 females, mean age = 26.32, SD = 5.68, range 20–39) were recruited. All participants had normal or corrected-to-normal vision and completed the Spiel Berger State-Trait Anxiety Inventory (STAI) prior to the experiment to control for potential anxiety-related effects on pupil responses. Written informed consent was obtained, and participants were compensated after completing the study. The protocol was approved by the Ethics Committee of Iran University of Medical Sciences. (IR.IUMS.REC.1399.2901).

Stimuli and Apparatus

Facial stimuli were selected from the Warsaw Set of Emotional Facial Expression Pictures (Olszanowski et al., 2014), which includes seven emotional states (fear, joy, disgust, anger, surprise, sadness, neutral) and neutral expressions. To control for luminance effects on pupil size, images were standardized using Photoshop (Adobe Inc.): backgrounds were replaced with uniform gray, and stray hair/features were removed. Luminance and histograms were matched across all stimuli using the SHINE Toolbox (Willenbockel et al., 2010) in MATLAB (MathWorks Inc.). Twenty identities (10 male, 10 female) were selected as stimuli.

The experiment was programmed in PsychToolbox-3 (Brainard, 1997) and displayed on a 24-inch monitor (60 Hz refresh rate). Pupil size was recorded using an EyeLink 1000 eye tracker (SR Research Ltd.) at 500 Hz sampling rate. Participants were seated 60 cm from the monitor, with head position stabilized by a chin rest. The eye tracker was calibrated before each session using a 9-point calibration procedure in MATLAB, and validation ensured error < 0.5° of visual angle.

Facial Emotion Perception Task

The task comprised two blocks: conscious perception and unconscious perception. In the conscious perception block, emotional faces (7 emotions × 2 genders = 14 stimuli) were presented for 1000 ms. In the unconscious perception block, emotional faces were displayed for 50 ms (below conscious recognition thresholds; Morris et al., 1998) and immediately masked by a neutral face of the same identity for 950 ms using backward masking. Each block included 210 trials (14 stimuli × 15 repetitions), presented in random order. As shown in Figure 1, each trial began with a 1000-ms fixation cross to stabilize baseline pupil size, followed by emotional face presentation (1000 ms for conscious; 50 ms + 950 ms mask for unconscious). After a 500-ms delay (applied only in the conscious block to enhance perception opportunity), participants were presented with a forced-choice response screen where they selected the perceived emotion from seven options arranged circularly. Participants completed 10 practice trials before each block to familiarize themselves with the task. Both blocks lasted approximately 20 minutes, with matched repetition rates and timing.

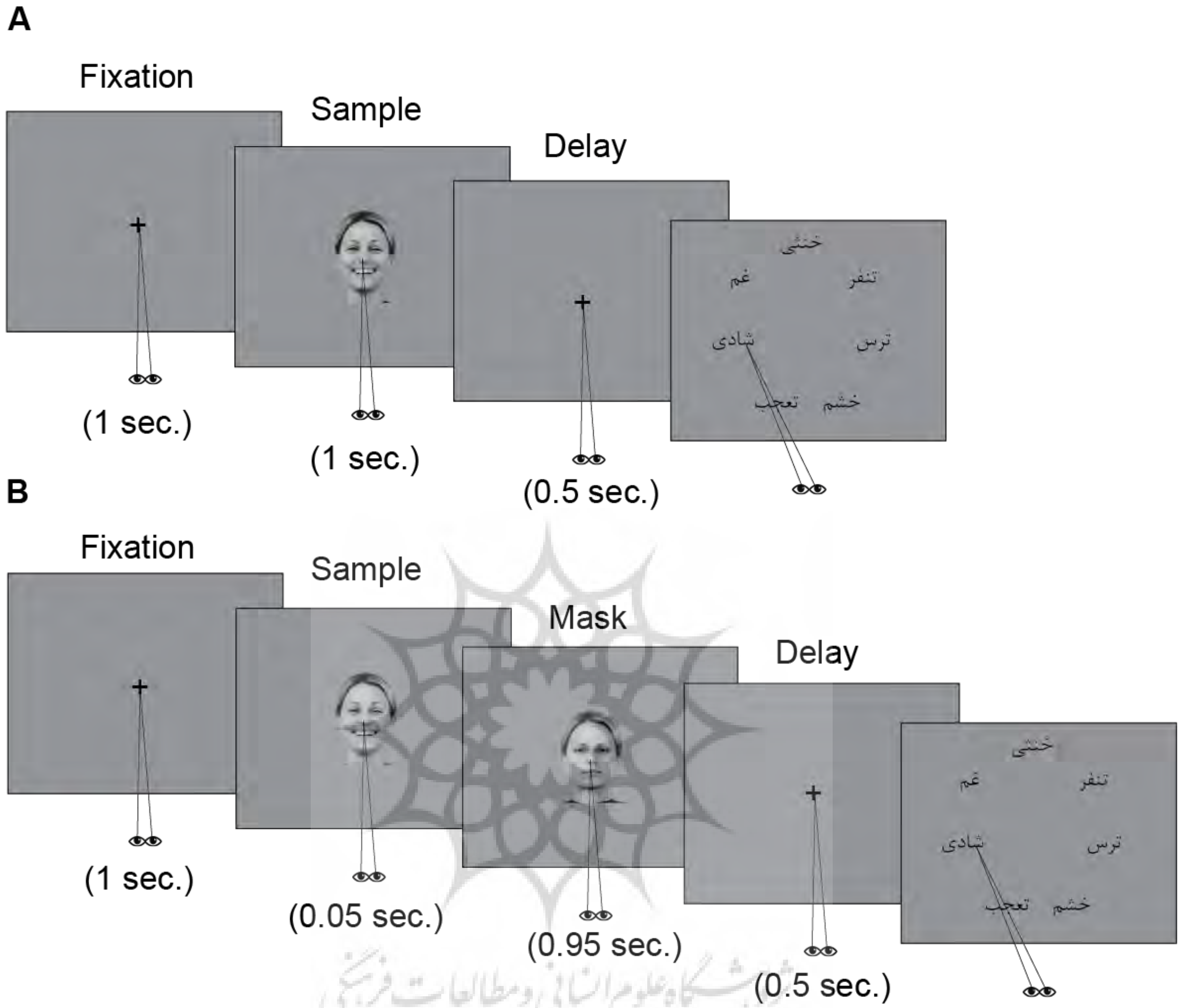

Figure 1. The schematic description of the trial sequences for behavioral tasks

(A) For conscious facial expression perception blocks, each trial began with a 1000 ms fixation cross, followed by a 1000 ms presentation of a facial expression, and then a 500 ms fixation cross. Then a response page appeared, and participants responded by saccadic eye movement to select the desired emotion name (خنثی = neutral, غم = sadness, شادی = happiness, تـ. ب. = surprise, خشـ. = anger, ترس = fear, تنفـ. = disgust) and pushed the response key on the keyboard to finalize the response. **(B)** In unconscious facial expression perception trials, a 1000 ms fixation cross preceded a facial expression presented for only 50 ms, which was then masked by a neutral image of the same face for 950 ms, followed by a 500 ms fixation cross. Then the response page appeared until the participant made a response.

General linear modeling of pupil response

Pupil responses were analyzed using models with 6 or 8 parameters for conscious and unconscious conditions. The Pupil Response Estimation Toolbox (PRET) (Denison et al., 2020) was utilized for parameter estimation, including internal signal amplitudes and latencies, task-related response amplitudes, linear drift parameters, and baseline shifts. Each event-related signal was characterized by amplitude and latency parameters, reflecting the strength and timing of the internal signal and associated pupil response component, respectively.

Statistical analysis

Data were tested for normality using the Shapiro-Wilk test. As the data violated assumptions of normality, non-parametric tests were employed: the Wilcoxon signed-rank test for pairwise comparisons and the Kruskal-Wallis test for overall analysis. For significant Kruskal-Wallis results, post-hoc comparisons were conducted using Dunn's test with a Bonferroni correction. All analyses were conducted using MATLAB (MathWorks Inc.).

Results

The average performance of participants in both conscious and unconscious states, along with other analysis was calculated (Figure 2). Generally, participants exhibited superior performance in the conscious state ($p < 0.05$), surpassing a 70% score. The lower performance in the unconscious state was attributed to task difficulty. A Kruskal-Wallis test uncovered significant differences among various emotions in the conscious state ($p < 0.01$). Post-hoc analysis (Dunn's test) highlighted differences between anger and happiness, fear and happiness, as well as neutral and surprise ($p < 0.05$). Similar tests conducted for the unconscious state ($p < 0.01$) indicated a noteworthy disparity, particularly between happiness and all other emotions, except for neutral and surprise. Additionally, significant distinctions were observed between neutral and all emotions, and surprise with anger and sadness ($p < 0.05$).

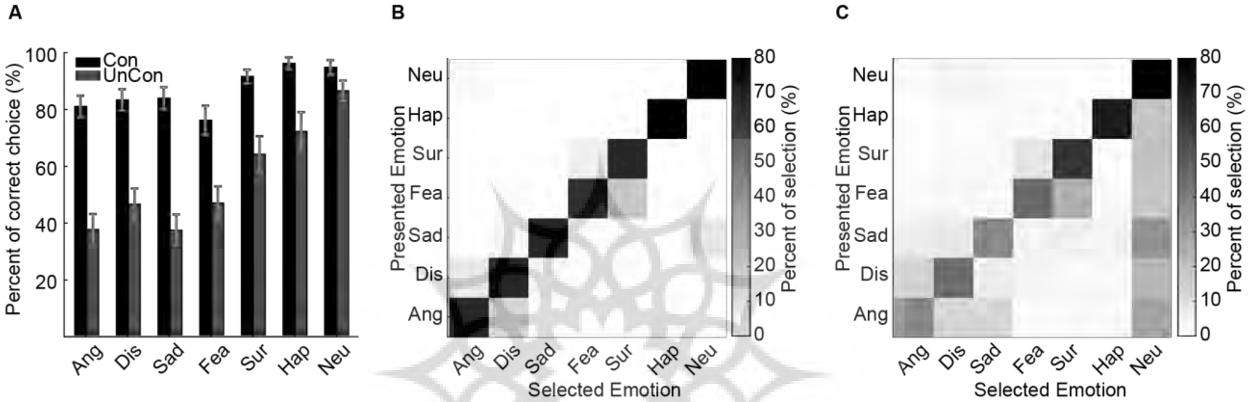

Figure 2. Behavioral performance and confusion matrix.

(A) The average performance of participants in conscious and unconscious perception for each emotion. Error bars represent the standard error of the mean. As expected, in unconscious perception, performance is lower due to the increased difficulty of the task. **(B)** Confusion matrix for the percentage of selection of emotions in the conscious state. In this figure, the vertical axis indicates the emotion displayed. In contrast, the horizontal axis represents the emotion selected by the participant, and the colors from white to black indicate the selection percentage. The main diagonal determines the correct performance, where the emotions presented and selected are the same. **(C)** Confusion matrix for the percentage of selection of different emotions in the unconscious state. As seen in the figure, there is a significant percentage of neutral responses instead of the displayed emotional expression in all emotions due to the presentation of a neutral mask.

In Panels B and C, the confusion matrices illustrate performance errors, revealing biases towards specific emotions. The conscious state matrix (Panel B) highlights challenges in distinguishing fear and surprise (19.95%) and anger and hate (14.58%). Notably, 8.59% of hate errors were misattributed to anger, while 5.87% of surprise errors were associated with fear. Although participants correctly identified sadness in 82.61% of cases, 8.54% of remaining trials were selected neutral. Happiness trials yielded the highest accuracy (94.79%) without discernible biases. Overall, participants exhibited performance biases despite pre-experiment training–

The confusion matrix delineating the unconscious state is presented in Panel C. Similar patterns to those observed in the conscious state manifest, notably biases between fear and surprise, and anger and hate. Given the neutrality of the mask, participants exhibited discernible errors by selecting the neutral state, instead of the correct emotion. Comparisons between the conscious and unconscious states reveal subtle distinctions. For instance, misattribution between sadness and anger, as well as sadness and hate, were notably elevated (5.97 and 7.75, respectively). Correct selection of happiness occurred significantly less frequently than the conscious state

(71.03). Similarly, fear was chosen correctly at a diminished rate (46.02), with 24.72% of the remaining inaccuracies pertaining to surprise.

Pupillometry Results

Pupil size was measured in both conscious and unconscious states, revealing a conspicuous pattern of suppression in the conscious state and enhancement in the unconscious state. Notably, there is an initial increase in pupil size within the first 500 ms for both states. In conscious trials, the pupil size experiences suppression, attributed to cortical networks inhibiting further changes through inhibitory back-projection. Conversely, this trend is absent in the unconscious state, where pupil size demonstrates an escalating slope. Furthermore, distinctions between rise time and pupil size across different states are observed.which are discussed in subsequent figures.

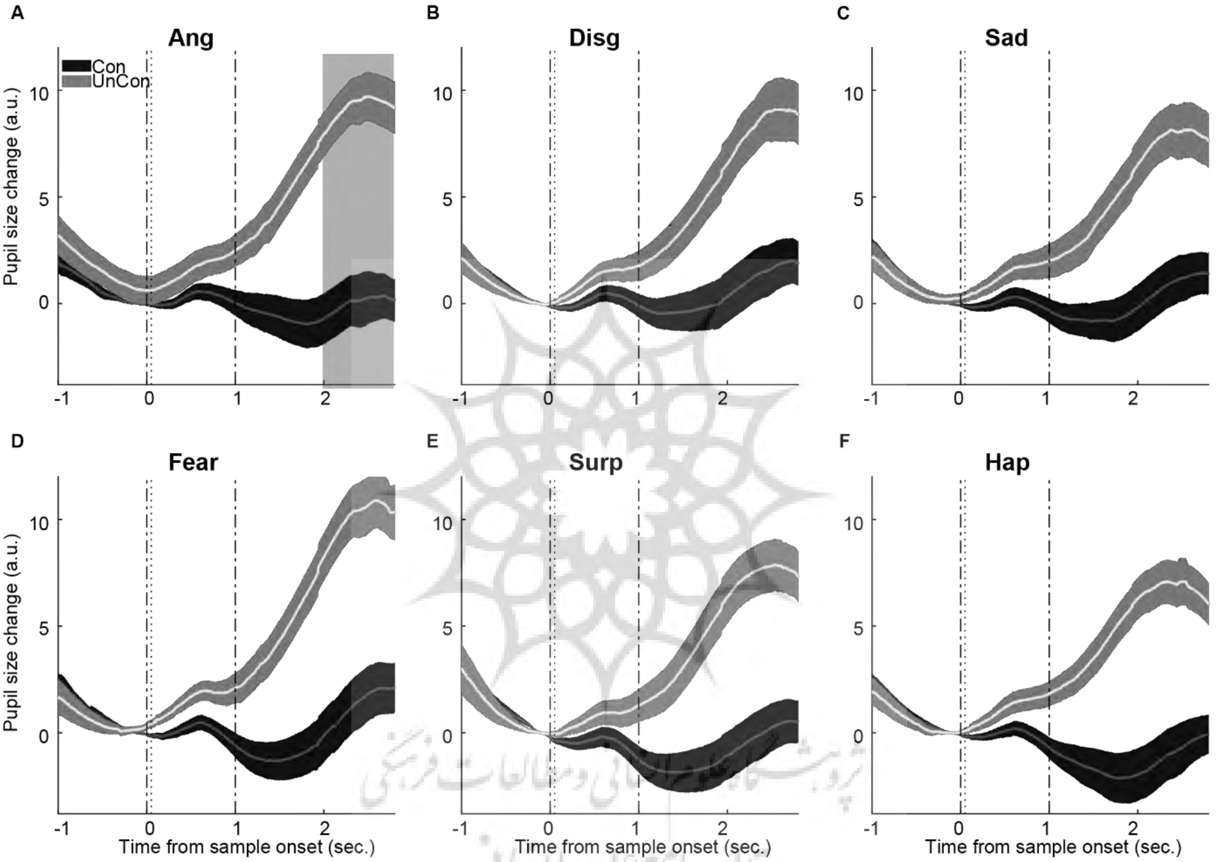

Figure 3. Modulation of pupil size changes for different emotions during conscious and unconscious perception The lighter shades represent pupil size changes during unconscious detection tasks, while the darker shades represent those during conscious detection tasks. As shown in the figure, all emotions elicit more significant changes in pupil size during unconscious perception than conscious perception. Additionally, there appears to be a difference in pupil dilation for different emotions, and the rise time for each emotion varies. The shaded area in the first plot represents the time interval during which the most significant changes in pupil size occur (between 2000 and 2800 ms after stimulus onset), and it has been used for further analysis.

Panel A displays the peak pupil size for correct trials in both conscious and unconscious states. No discernible change was observed in neutral trials. A Wilcoxon signed-rank test revealed significant differences for two states of consciousness for each emotion ($p < 0.00$), except for neutral ($p = 0.07$). ANOVA analysis did not indicate significant differences between emotions in the conscious state. However, there was a significant disparity in peak pupil size during the unconscious state. Post-hoc analysis identified this difference specifically between neutral and fear conditions.

In Figure 4 (B and C), the confusion matrix for peak pupil size in both states of consciousness is presented. Unlike Panel A, Panels B and C encompass all trials, not solely the correct ones. The vertical axis denotes the presented emotion, while the horizontal axis represents the selected emotions. The main diameter of the confusion matrices signifies the correct trials. As mentioned, the matrices include instances where the wrong emotion was selected, but trials with fewer than 5 errors were disregarded due to potential external factors. Noteworthy is the absence of significant changes in the conscious state (Panel B), except for instances where participants selected fear. Conversely, the unconscious state exhibits significant pupil dilation, even when emotions are incorrectly selected. Notably, when fear and surprise are chosen correctly or incorrectly, there is a discernible increase in pupil size. The accompanying histogram illustrates presented and selected emotions. In the conscious state, major changes are absent. However, the confusion matrix for the unconscious state reveals that pupil dilation are determined by the selected (perceived) emotions rather than the presented ones. The histogram indicates that the highest recorded pupil size change occurs when the perceived emotion is fear.

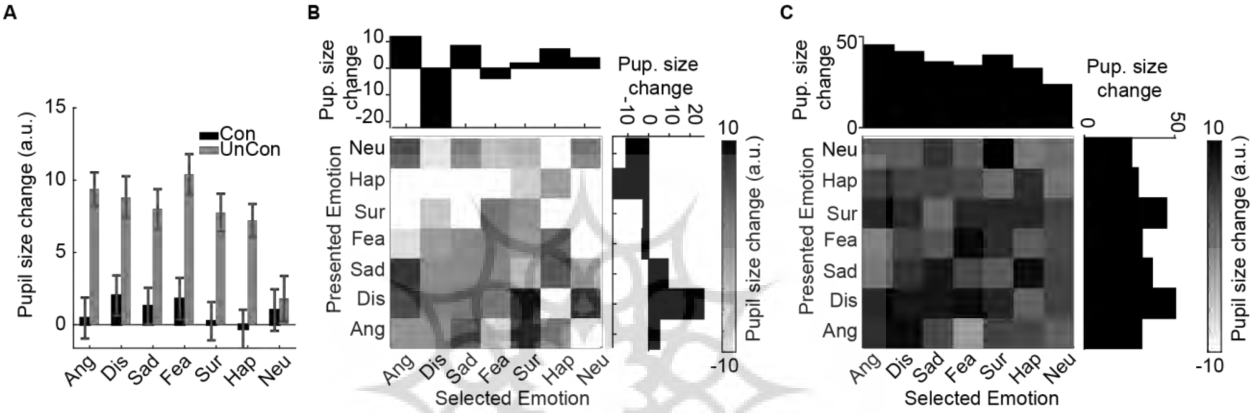

Figure 4. Difference between pupil size changes in different emotions

(A) This panel demonstrates the variations in pupil size for trials where the correct answer was selected for both conscious and unconscious tasks. There is a minimal observable change in pupil size for neutral stimuli in both conscious and unconscious states and for emotional stimuli in the conscious state. Error bars represent the standard error of the mean. **(B)** Confusion matrix of pupil size change for different emotions in the conscious state. The upper barplots demonstrate changes in pupil size when the target emotion is selected, irrespective of the particular emotion displayed. The barplots on the right illustrate variations in pupil size when a specific emotion is displayed, regardless of which emotion is selected. **(C)** Confusion matrix of pupil size change for different emotions in the unconscious state.

In the conscious state, when the presented stimulus is positive and the subject mistakenly selects a negative emotion, there is a decrease in pupil size. Also, there are different pupil size changes with the emotion of disgust. In the unconscious state, there is a more significant increase in pupil size overall. The unconscious state exhibits significant pupil size changes, even when emotions are incorrectly selected. Notably, when fear and surprise are chosen correctly or incorrectly, there is a discernible increase in pupil size, with more pronounced changes during negative emotions. Disgust evokes a greater increase when it is the presented emotion. Using peak response alone may not decode the types of emotion and their processing speed accurately. We utilized modeling tools to investigate these parameters more precisely.

General linear modeling of pupil response

Using the modeling, we investigated the different components of the task in the production of pupil response. Based on the work of Hoeks and Levelt (1993), pupil response models typically assume two points (Hoeks & Levelt, 1993). First, the models assume a stereotyped pupil response function (PuRF) like a gamma function, which describes the time series of pupil dilation in response to a brief event. Second, the models assume that pupil responses to different trial events sum linearly to generate the pupil size time series; that is, they are general linear models (GLMs) (Figure 5). Using this model, we aimed to separate different components and assess their contributions to pupil response. Generally, three important components should be evaluated: task-related response, amplitude, and latency of emotional stimuli presentation.

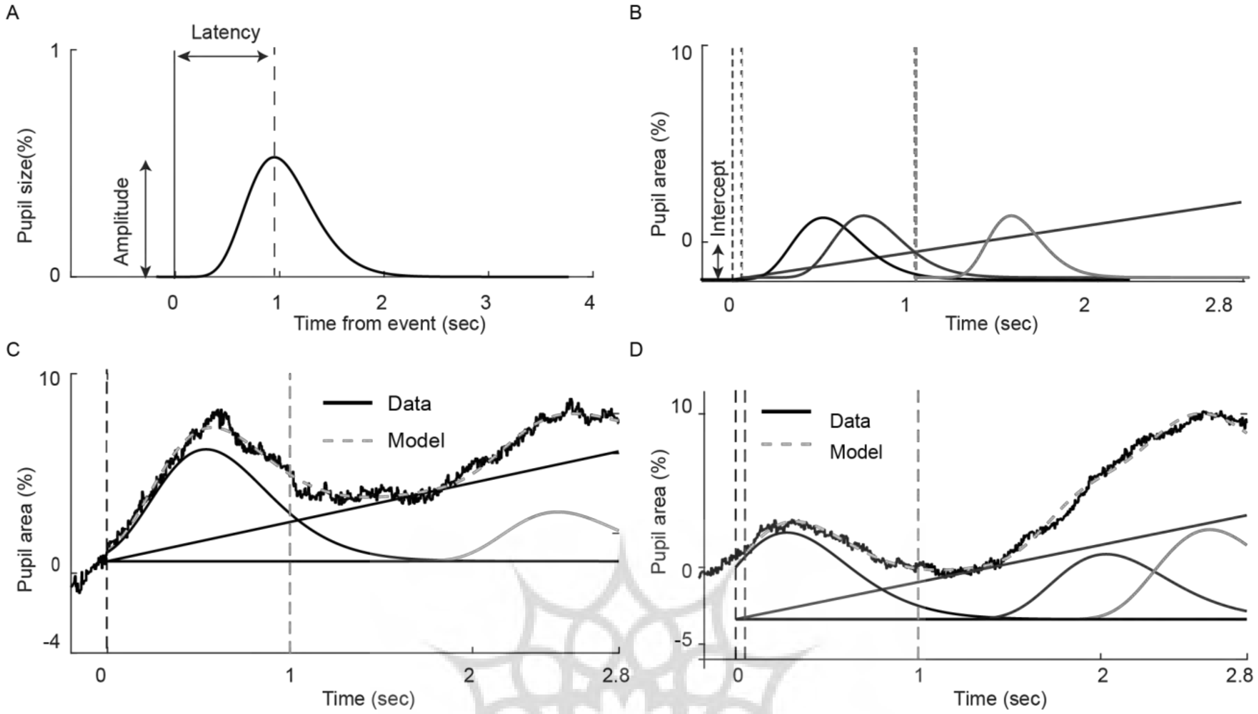

Figure 5. The modeling of the pupil time series.

(A) a Pupil response function, which describes the pupillary response to an event. The canonical function, a gamma function with n = 10.1 and tmax = 930 ms (vertical dashed line), is shown. **(B)** Trial events hypothesized to drive pupil dilation. Each trial event (visual stimuli) is modeled as a delta function (vertical dashed lines) with some amplitude and some latency with respect to the event. For conscious we have two events at 0 sec, onset of stimulus and 1 sec, offset of stimulus and for unconscious we have one event more presentation of mask at 5o ms after stimulus onset. As line (slop and y- intercept), task-related signal could also be modeled. Shown here is in a solid line. **(C, D)** The pupil time series across (black line) is modeled in two steps. First, each internal signal time series is convolved with the pupil response function to form component pupil responses. Second, the component pupil responses are summed to calculate the model prediction (gray dashed line). Parameters of the model, such as the amplitudes and latencies of the internal event signals, are fit using an optimization procedure. (C) is for sample conscious and (D) is for unconscious trials.

We assumed a linear function as the task-related component for each trial and one baseline shift parameter. These parameters differed for conscious and unconscious states (Figure 6A-B). For the conscious state, angry and surprise have negative slopes, while fear has a positive slope. For the unconscious state, the slope parameter is positive except for neutral, in which there was no emotion. There were no differences in task-related slopes among unconscious emotions. The baseline value is also negative for unconscious emotions and disgust emotion in the conscious state.

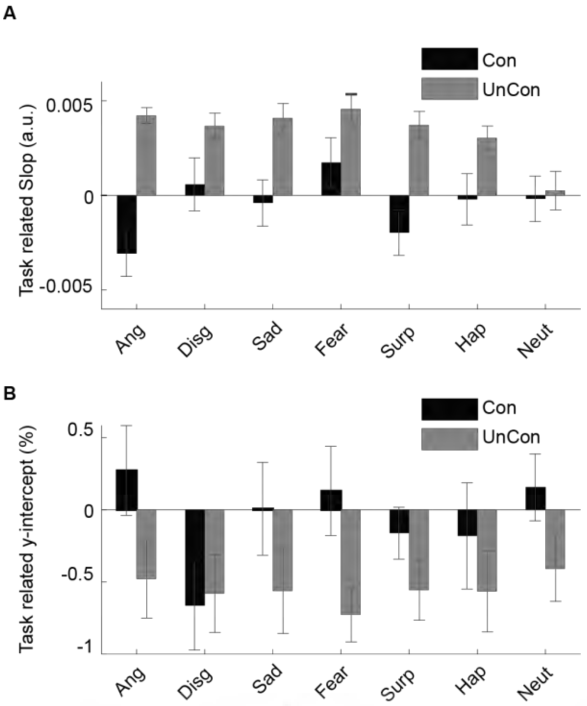

Figure 6. Task related Model parameters over subjects. Tasl related parameters, upper plot slope of line and lower plot y- intercept.

Each event had a response function with an amplitude parameter and a latency parameter associated with it. The amplitude parameter was the value of the nonzero point of the delta function and indicated the magnitude of the internal signal, determining the magnitude of the component pupil response associated with it (Figure 7). The first event for each state is the emotion-related event (amp1 Con and amp1 UuCon). For conscious states, the emotion-related amplitude did not differ between emotions. Similarly, in unconscious states, the emotional response did not differ between emotions.

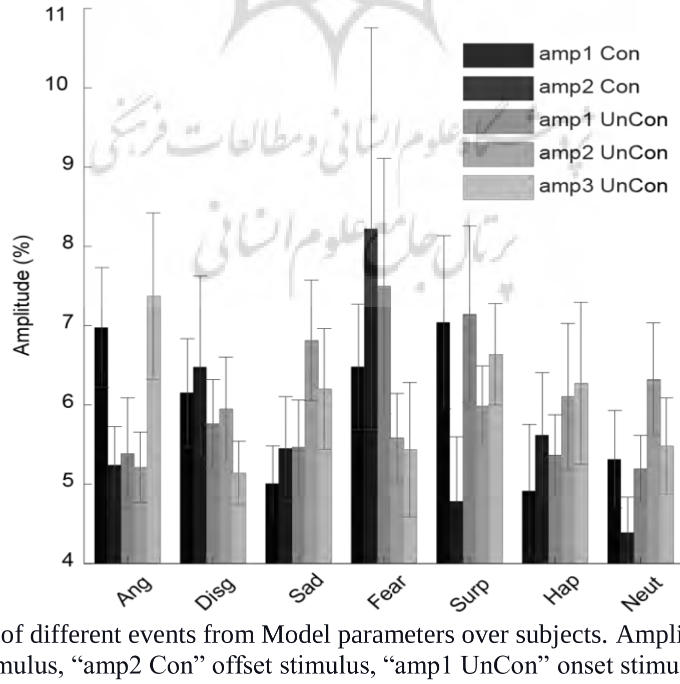

Figure 6. The effect of different events from Model parameters over subjects. Amplitude for different events “amp1 Con” onset stimulus, “amp2 Con” offset stimulus, “amp1 UnCon” onset stimulus, “amp2 UnCon” onset mask and “amp3 UnCon” offset stimulus.

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The latency parameter was the time (in ms) of the nonzero value, relative to the time of its corresponding event. The pupil latency reflected the speed of the emotional response (Figure8). In conscious states, the emotion-related latency did not differ between emotions. Happy and angry were the fastest, while surprise and neutral were the slowest in conscious states. In unconscious states, sad, fear, surprise, and happy were the slowest responses, while disgust was the fastest.

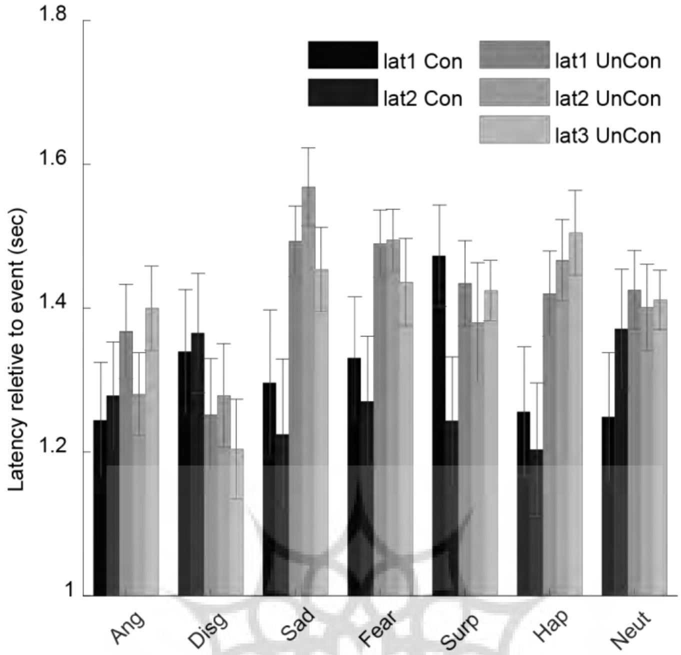

Figure 8. The speed of different events from Model parameters over subjects. latency for different events lat1 Con" onset stimulus, "lat2 Con" offset stimulus, "lat1 UnCon" onset stimulus, "lat2 UnCon" onset mask and "lat3 UnCon" offset stimulus.

Correlation analysis (Spearman's rank) between peak pupil size and demographic factors (age, sex, education level, STAI score) showed no significant correlations (all $p > 0.05$), indicating that pupillary responses were not confounded by these variables.

Discussion and Conclusion

This study aimed to investigate the behavioral and pupillometric correlates of conscious and unconscious processing of six basic emotions. We hypothesized that (1) recognition accuracy would vary across emotions, with happiness being the most identifiable; (2) distinct pupil dilation patterns would emerge for different emotions, with fear eliciting the strongest response; and (3) pupil dilation would be greater for unconsciously perceived stimuli due to reduced cortical inhibition.

Our results confirm these hypotheses. We found that recognition accuracy was highest for happiness in both states, supporting its role as a primordial and easily processed emotion. Furthermore, pupillometry revealed a clear dissociation between states: unconscious perception was characterized by enhanced pupil dilation, while conscious perception showed relative suppression. This pattern is consistent with the proposed model where conscious, cortical processing inhibits subcortically-driven autonomic responses [**Cite e.g., Tamietto & de Gelder, 2010**]. Notably, fear elicited the most robust pupillary response, especially when perceived unconsciously, underscoring the salience of threat-related stimuli even in the absence of awareness.

It is important to note that we found no significant correlations between pupillary responses and demographic factors such as age, gender, education level, or trait anxiety. This suggests that the core effects of emotional processing on autonomic arousal, as measured by pupillometry, are robust across these individual differences in our healthy sample.

The findings reveal a consistent increase in pupil size during emotional perception compared to neutral stimuli, irrespective of valence, supporting the hypothesis that emotional processing imposes cognitive load (Partala et al., 2003). Critically, these pupillary changes were independent of low-level stimulus properties (e.g., luminance), reinforcing their link to emotional arousal. In unconscious trials, heightened pupil dilation during the response period aligns with evidence that facial expressions influence autonomic responses even without conscious awareness (Eastwood & Smilek, 2005; Tamietto et al., 2009). Notably, unconscious stimuli elicited larger pupil changes than conscious ones, potentially reflecting heightened subcortical arousal (Tamietto & de Gelder, 2010) .

The observed unconscious pupil dilation may not solely stem from cortical inhibition. Competing explanations must be considered, such as cognitive load, as increased mental effort during unconscious processing could drive pupil dilation. Prior work demonstrates that cognitive demand amplifies pupillary responses (Kiefer et al., 2016; Gavas et al., 2017), suggesting that the effort to process masked stimuli might contribute to the observed effects. Another possibility is covert attention, as unconscious shifts in focus toward emotional stimuli might mediate dilation (Mathot et al., 2013). Disentangling these mechanisms requires future studies that isolate attention and cognitive load from inhibitory cortical-subcortical interactions .

The transient pupil size reduction approximately one second after unconscious stimulus onset (Figure 3) may reflect inhibitory feedback from cortical to subcortical regions (Tamietto & de Gelder, 2010). However, the subsequent rebound in dilation could arise from fading inhibition and reactivation of excitatory subcortical pathways. This interplay underscores the dynamic neural coordination underlying unconscious emotional processing. Caution is warranted when extrapolating these results, as age-related differences in emotion recognition (Calder et al., 2003) and individualized perceptual thresholds (Tsikandilakis et al., 2021) suggest our findings may not generalize across demographics. For instance, younger adults typically outperform older adults in facial recognition tasks, except for disgust (Calder et al., 2003). Furthermore, fixed experimental thresholds risk conflating subliminal perception with methodological bias, as Tsikandilakis et al. (2021) demonstrated using Bayesian methods. Future work should tailor thresholds to participants and emotions to mitigate such biases .

The GLM approach revealed temporal disparities in pupil responses: conscious trials showed emotion-specific latencies (e.g., happiness: 320–335 ms), while unconscious responses were slower overall (peaking at 510–520 ms for fear/surprise). These patterns highlight distinct temporal dynamics between conscious and unconscious processing, though amplitude consistency suggests comparable arousal magnitudes .

In conclusion, this study elucidates how conscious and unconscious emotional perception differentially engage pupillary and neural mechanisms. While conscious recognition prioritizes cortical accuracy, unconscious processing amplifies subcortical arousal, reflected in heightened pupil dilation. Fear and happiness emerged as pivotal emotions, with fear triggering)robust unconscious responses even when misclassified. These findings underscore the dual pathways of emotional processing and emphasize the need for demographic-sensitive methodologies in future research. By addressing unresolved questions such as the roles of cognitive load and attention this work advances frameworks for studying social perception in both typical and clinical populations5

Declarations

Author Contributions

All authors contributed actively to the conception, design, and execution of the research.

Data Availability Statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Ethical considerations

This study was conducted in accordance with the ethical standards of the Declaration of Helsinki. The research protocol was reviewed and approved by the Ethics Committee of Iran University of Medical Sciences (Approval Code: IR.IUMS.REC.1399.2901). All participants were informed about the general aims and procedures of the study and provided written informed consent prior to participation. Confidentiality and anonymity of the participants' data were fully maintained throughout the research process.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this research.

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