Title: Context-Dependent Modulation of Visual Recognition by Conscious and Unconscious Priming

Authors: Samaneh Navab[1], Reza Khosrowabadi[1,*], Mohammad-Reza A. Dehaqani[2,3,*]

1. *Institute for Cognitive and Brain Sciences, Tehran, Iran.*
2. *College of Engineering, School of Electrical and Computer Engineering, University of Tehran, Tehran, Iran.*
3. *School of Cognitive Sciences, Institute for Research in Fundamental Sciences (IPM), Tehran, Iran.*

***Corresponding Author**: Reza Khosrowabadi, Institute for Cognitive and Brain Sciences, Tehran, Iran. Email: r_khosroabadi@sbu.ac.ir. Mohammad-Reza A. Dehaqani, College of Engineering, School of Electrical and Computer Engineering, University of Tehran, Tehran, Iran & School of Cognitive Sciences, Institute for Research in Fundamental Sciences (IPM), Tehran, Iran. Email: dehaqani@ut.ac.ir

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Abstract

Despite extensive study, the ways in which conscious and unconscious priming influence visual perception remain only partially understood. In this work, we examine their distinct effects across multiple experimental conditions within a binocular rivalry paradigm, in order to provide a more comprehensive perspective on identity and category recognition. Participants were presented with word or image primes, followed by a name–picture verification task in which faces or animal bodies served as targets. Although conscious priming has been shown to facilitate identity recognition while interfering with category perception, the precise distinction between conscious and unconscious states and the mechanisms underlying unconscious priming requires more detailed analysis and investigation. Left hemispheric processing was one of the influential factors in distinguishing the conscious and unconscious priming effects. Interestingly, we observed a negative correlation between conscious and unconscious perception during identity recognition, highlighting the condition-dependent modulation of visual perception in the priming paradigm. Awareness showd from the regression analyses as the strongest predictor of priming magnitude, with recognition level playing a secondary role. More broadly, our findings demonstrate that visual perception circuits are modulated in a condition-dependent manner, underscoring how awareness and trial context jointly shape recognition processes.

Keywords: Conscious Priming, Unconscious Priming, Visual Perception, Identity Recognition, Category recognition, Support Vector Regression, Sensitivity analysis

Introduction

Priming is a central mechanism in visual perception, shaping how prior exposure to stimuli influences subsequent processing at both behavioral and neural levels (Balconi, 2006; Dehaene et al., 1998; Jiang et al., 2007; Marsolek, 1999; Stein et al., 2020). While extensive work has characterized general priming effects, the ways in which conscious and unconscious priming distinctly modulate identity versus category recognition are not well understood (Amihai et al., 2011; Chien et al., 2023; Moradi et al., 2005a). Most prior research has treated these processes in isolation, often ignoring how awareness interacts with different prime modalities, such as words versus images, or with target types, including faces and animal bodies.

Recognition at the identity level requires precise differentiation of individual exemplars, whereas category recognition relies on broader, abstract representations of object classes (Johnson & Mervis, 1997; Rosch et al., 1976). Neuroimaging and electrophysiological studies indicate that category information is encoded rapidly in the inferior temporal cortex, whereas identity recognition depends more on feedback pathways supporting fine-grained processing (Dehaqani et al., 2016). Despite this distinction, the extent to which conscious and unconscious priming modulate these processes across awareness states remains largely unexplored.

Evidence from unconscious priming demonstrates that masked stimuli, including words and images, can facilitate subsequent perception and evoke category-specific neural activity, such as Fusiform Face Area activation for faces (Breitmeyer et al., 2005; Dehaene et al., 2001; Kouider et al., 2009; Weibel et al., 2013). Emotional expressions of unseen faces can trigger amygdala responses, yet successful identity recognition often requires conscious perception (Moradi et al., 2005a; Pessoa et al., 2005). Clinical phenomena, including blindsight and unilateral neglect, further illustrate that category-level processing can occur without awareness, whereas identity-level recognition is constrained by conscious access (Berti & Rizzolatti, 1992; Trevethan et al., 2007). Collectively, these findings highlight a critical gap: the differential impact of conscious versus unconscious priming on identity and category recognition remains unresolved.

To address this, we employed a binocular rivalry paradigm adapted from Navab et al, 2025 that allowed precise manipulation of prime awareness by presenting stimuli to one eye while suppressing perception with a rival input (Navab kashani et al., 2025). Participants then performed a name–picture verification task using faces or animal bodies, enabling the examination of priming effects across prime and target types. Regression analyses quantified the contributions of awareness, prime type, target type, and hemispheric asymmetries, providing a comprehensive assessment of factors driving recognition performance.

Our results demonstrate that unconscious priming showed the reverse pattern for identity recognition. These findings reveal that conscious and unconscious priming differentially modulate visual recognition through distinct neural pathways. Overall, the present experiment indicates that the impact of individual factors is highly condition-dependent, with variations across experimental contexts shaping the way priming influences perception.

Method

Participants

Twenty-two right-handed adults (14 male; mean age = 35.7 years, range between 32 to 43), all healthy and unfamiliar with the task, took part in the experiment. Each reported normal or corrected-to-normal vision and gave written informed consent. The study complied with the Declaration of Helsinki, and ethical approval was obtained from the Shahid Beheshti University Ethics Committee (ID: IR.SBU.REC.1398.047).

Stimuli and Apparatus

The experiment was conducted in a dimly lit room, with participants seated 64 cm from a monitor (1920 × 1080 resolution, 144 Hz refresh rate, 1 ms response). Visual input was delivered through a mirror stereoscope attached to a chinrest, ensuring stable alignment. Stimuli were presented against a uniform gray background.

Stimuli consisted of Persian words and grayscale images representing four classes—women, men, cats, and dogs—evaluated at two recognition levels (identity and category). Each category included its name label, a symbolic category image, and three identities represented as both words and pictures (Navab kashani et al., 2025). Continuous Flash Suppression (CFS; (Tsuchiya et al., 2009) was generated in MATLAB Psychtoolbox (Brainard, 1997) using Mondrian noise patterns (colored squares flashing at 20 Hz).

Face and animal stimuli were collected from online image searches and luminance-matched with the SHINE Toolbox. Except for primes (4° visual angle), all stimuli subtended 6° to avoid retinotopic overlap (Posner & Cohen, 1980, 1984). Non-prime stimuli were framed by a textured black–white border extending to 6.5° (see Figure 1)

Procedure and Design

Awareness was manipulated via binocular rivalry combined with CFS, a method offering extended suppression and precise perceptual control compared to standard masking (Axelrod et al., 2015; Tsuchiya & Koch, 2005). In this setup, competing images presented to each eye lead to dominance of one stimulus while the other remains suppressed yet influential (Blake, 2001; Fang & He, 2005). Mondrian noise, flashing at 20 Hz, maintained suppression for up to 50 s, allowing subliminal primes to be presented in one eye. Unlike b-CFS paradigms (Jiang et al., 2007), this design assessed the impact of subliminal primes on subsequent tasks rather than suppression break. Primes were shown foveally but lateralized to one visual field to assess hemispheric asymmetries.

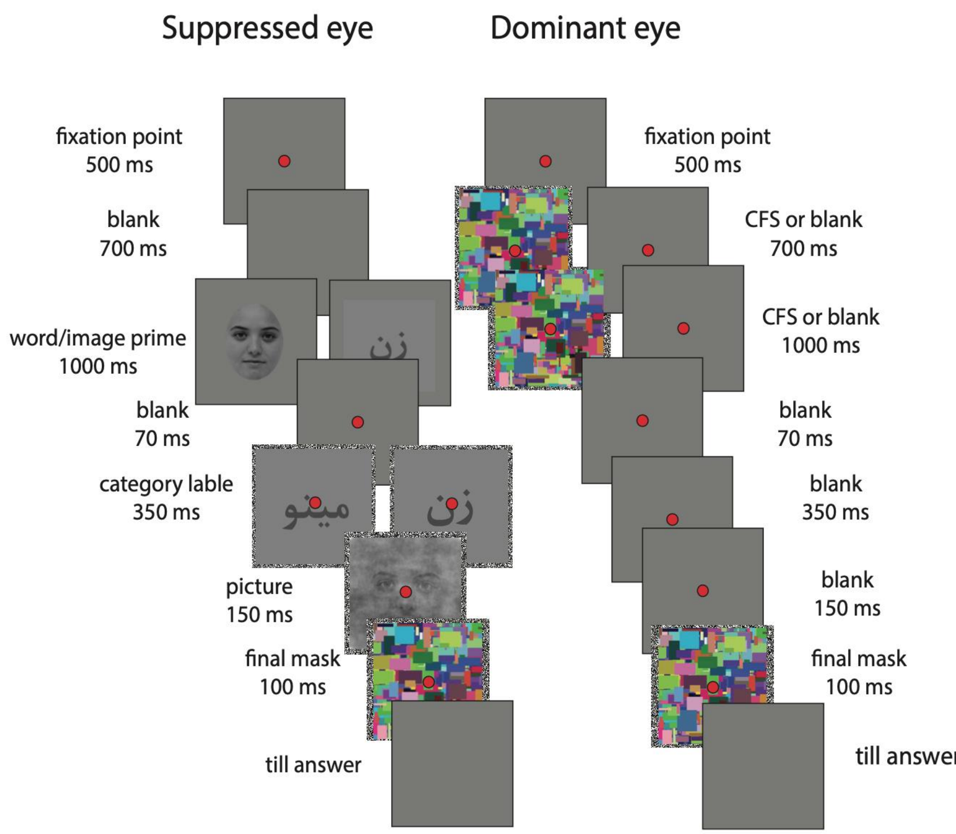

Figure 1. Experimental paradigm
Illustration of the binocular rivalry task with Continuous Flash Suppression (CFS). In this setup, one frame was delivered to the suppressed eye (left/right visual field) and the other to the dominant eye (right/left visual field), enabling comparison between conscious (no CFS) and unconscious (CFS) conditions. Primes—either words or images—were presented at the identity or category level, followed by a name–picture verification task.

Experimental Design

To test identity and category recognition, we employed a name–picture verification paradigm (Collin & Mcmullen, 2005). Participants judged whether a word label (e.g., “Bulldog” for identity or “Dog” for category) matched a subsequent picture, with match/mismatch trials balanced. Identity trials required subordinate-level recognition (e.g., “Bulldog” followed by Bulldog or Doberman), while category trials required basic-level recognition (e.g., “Dog” followed by Dog or Cat). Mismatch conditions used within-category distractors for identity and cross-category distractors for category, avoiding overlap at the superordinate level. Primes were either images or words, with relevant primes consistent with the target and irrelevant primes drawn from unrelated categories or higher levels.

Participants first underwent training without stereoscopes or primes, learning to identify categories through paper-based practice. Feedback was provided via fixation color (green = correct, red = incorrect), and only those reaching >95% accuracy continued.

The main task, conducted without feedback, required right-hand keypresses (right = match, left = mismatch) while fixating centrally. Prime and target presentations were lateralized to left/right visual fields. In unconscious conditions, primes were suppressed by CFS noise in the contralateral field. The CFS paradigm randomly suppressed primes across eyes, effectively balancing eye dominance across conditions. Each trial began with 500 ms fixation, followed by 1700 ms of either CFS (unconscious) or blank (conscious). Primes appeared gradually for 1000 ms at low contrast (0.15%–0.4%). After a 70 ms blank, a word label (350 ms) was followed by a picture (150 ms), which was immediately masked with bilateral Mondrian noise (100 ms). Conscious primes were visible for 1000 ms without CFS (Navab kashani et al., 2025).

In this experimental framework, seven factors were manipulated in a factorial design, with each trial representing a unique combination of conditions and yielding both a reaction time (RT) and an accuracy measure. The factors included: Priming (relevant vs. irrelevant), Awareness (conscious vs. unconscious), Recognition level (identity vs. category), Prime type (image vs. word), Target type (face vs. animal), Visual field laterality (left vs. right), and Matchness (match vs. mismatch) that presented in intermixes trials. The target set comprised six exemplars—three male and three female faces, three cats, and three dogs—resulting in a total of 768 trials per participant.

Statistical Analysis

Trials with incorrect responses or RTs outside 50–6000 ms were excluded (<5%). Mean RTs per participant were computed, focusing on RT due to its sensitivity to priming. Planned comparisons were analyzed using two-tailed Wilcoxon signed-rank tests, and correlations between variables were examined with Pearson's r.

Prime Index (PI)

The Prime Index was defined as the difference in mean RT between trials with a relevant prime and trials with an irrelevant prime, computed separately for identity and category tasks. if relevant-primed RT = 400 ms and irrelevant = 450 ms, then PI = –50 ms

Priming Effect Difference (PED)

To examine differential priming effects, we analyzed 16 conditions combining prime properties: Laterality **(**Left/Right visual field**)**, target type (Face/Animal), Prime type (Word/Image), and recognition level (Identity/Category). For each condition (e.g., Left-Face-Word-Identity), we calculated eight PIs representing all combinations of these factors within that condition (e.g., Left: F-I-ID, F-W-ID, A-I-ID, A-W-ID, F-I-Ca, F-W-Ca, A-I-Ca, A-W-Ca). To compare two conditions, we computed the Pearson correlation between their respective sets of eight PIs. The Priming Effect Difference (PED) was defined as 1 minus this correlation coefficient, providing a robust measure of dissimilarity in priming effects across conditions. if correlation coefficient between animal and face conditions = -0.2, then PED = 1-(-0.2) = 1.2.

Support Vector Regression (SVR) for predicting the Prime Index:

To quantify the contribution of different experimental factors to reaction time (RT), we employed a Support Vector Regression (SVR) model with a radial basis function (RBF) kernel. SVR is a robust method for handling nonlinear relationships and is particularly effective in high-dimensional spaces (Smola & Schölkopf, 2004). The response variable was the Prime Index, defined as the difference in reaction times between the prime and the irrelevant prime conditions. The predictor variables included five experimental factors: Laterality **(**Left/Right visual field**),** Prime Type **(**Image/Word**),** Target Type **(**Face/Animal**),** Recognition Level (Identity/Category), and Awareness (Conscious/Unconscious)**.**

Before training the SVR model, all predictor variables were standardized using z-score normalization to ensure comparability and prevent dominance by variables with larger scales:

$$X' = \frac{\mathrm{X} - \mu_X}{\sigma_X}$$

where X′ is the standardized feature, μ_X is the mean, and σ_X is the standard deviation of the feature.

The SVR model was trained using epsilon-insensitive loss, which minimizes errors within a predefined margin ϵ and optimizes the following objective function (Vapnik, 1998):

$$\min_{w,b} \frac{1}{2} \parallel w \parallel^2 + \mathrm{C} \sum_{i=1}^{n} max(0, |y_i - f(X_i)| - \epsilon)$$

where w is the weight vector, b is the bias term, C is the regularization parameter, and f(X) represents the predicted response. The model was implemented using MATLAB’s fitrsvm function with an RBF kernel.

Sensitivity analysis for feature contribution

To assess the contribution of each factor, we conducted sensitivity analysis by systematically varying individual predictors while holding others constant and measuring the resulting changes in model predictions. Specifically, for each predictor X_i , we generated a range of values within the observed data limits and computed the corresponding predictions:

$$\hat{Y}(X_i) = f(X_1, \ldots, X_i, \ldots, X_n)$$

The sensitivity score for each factor was calculated as the standard deviation of the predicted values, reflecting the extent to which changes in that predictor influenced the response variable:

$$S_i = std(\hat{Y}(X_i))$$

To facilitate comparison, sensitivity scores were normalized:

$$S'_i = \frac{S_i}{\sum_{j=1}^{n} S_j}$$

Higher values indicate a greater influence of the predictor on the Prime Index. Sensitivity analysis provides an interpretable measure of feature importance without requiring explicit model assumptions (Saltelli et al., 2008).

Support Vector Regression (SVR) is a machine learning method that extends Support Vector Machines (SVM) to regression tasks by finding a function that best predicts a continuous response variable while maintaining a margin of tolerance ϵ around the true values (Smola & Schölkopf, 2004). Using a kernel function, SVR can model complex, nonlinear relationships between predictors and the outcome, making it particularly useful for psychophysical data where multiple interacting factors influence behavior.

Statistical significance testing

To assess whether each factor contributed significantly to the model, we performed bootstrap resampling (Tibshirani & Efron, 1993) with 500 iterations. For each bootstrap sample, we re-computed sensitivity scores, obtaining a distribution of values for each predictor. The statistical significance of each predictor’s contribution was evaluated using a test against zero, assuming a normal approximation.

Additionally, we performed pairwise comparisons between predictors to determine whether their contributions differed significantly. For each pair (i, j) we computed the distribution of the difference in sensitivity scores and the significance of these differences was assessed using the same test by means of normal approximation.

Results

We investigated the differential influence of conscious and unconscious priming on identity and category recognition within a binocular rivalry paradigm (Figure 1). Participants performed a name–picture verification task in which primes—either words or images—preceded target stimuli depicting faces or animal bodies, presented in the left or right visual field. Each target was paired with four possible labels: identity-matching, identity-mismatching, category-matching, or category-mismatching. The design included four prime conditions (relevant image, irrelevant image, relevant word, and irrelevant word), thereby manipulating both the level of recognition and the relevance of the prime. This fully factorial setup enabled us to assess the specific contribution of each factor.

As shown in previous studies (Navab kashani et al., 2025) priming exerts differential effects on identity and category recognition under conscious and unconscious conditions using a binocular rivalry paradigm. Under conscious priming, a clear dissociation emerged: identity recognition was facilitated (Figure 2A; PI_{id} = –104.5 ± 38.4 ms, p = 0.015), with faster RTs for relevant compared to irrelevant primes, indicating positive priming. In contrast, category recognition was impaired (Figure 2A; PI_{ca} = 57.7 ± 20.4 ms, p = 0.028), with slower RTs relative to irrelevant primes. This divergence (Figure 2A; ΔPI_{ca-id} = 162.2 ± 42.7 ms, p = 0.002) was robust and observed in nearly all participants (Figure 3B, C; 18/22), highlighting opposing priming effects under conscious conditions. No such dissociation was detected under unconscious priming, suggesting that these effects are contingent on awareness.

This pattern implies that identity and category recognition rely on distinct neural mechanisms, differentially modulated by conscious perception.

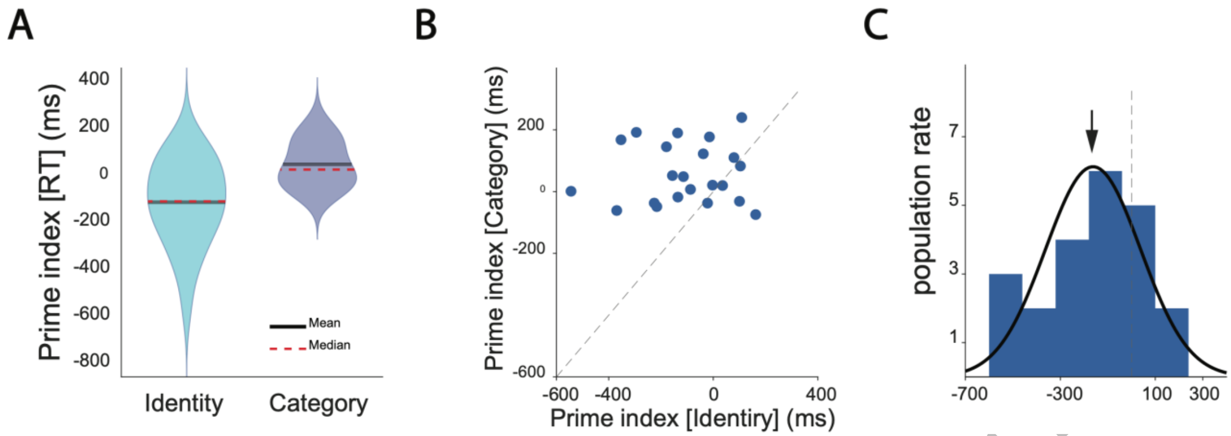

Figure 2: Conscious priming exerts distinct effects on identity and category recognition
(A) The Prime Index (PI), defined as the mean reaction time (RT) difference between relevant and irrelevant prime trials, diverged by recognition level under conscious priming. (B, C) The scatterplot and histogram illustrate inter-individual variability, with the majority of participants (18/22) exhibiting faster identity RTs and slower category RTs under conscious conditions.

Under unconscious priming, the mean Prime Index (PI) showed little differentiation between identity and category recognition (Figure S1: Unconscious: $\Delta PI_{ca-id} = -14.2 \pm 27.0$ ms, p = 0.520). To further elucidate these processes, we explored additional factors—prime type (word vs. image), laterality (left vs. right visual field), and target stimuli (faces vs. animals)—offering insights into the underlying brain systems and their condition-specific interactions.

Hemispheric modulation of conscious and unconscious priming in identity and category recognition

Although overall priming effects were absent under unconscious conditions, examining hemispheric processing revealed distinct patterns between conscious and unconscious states. We assessed these states across prime type (word vs. image), target type (face vs. animal), and visual field (left vs. right) using the Priming Effect Difference (PED) metric—defined as 1 minus the correlation coefficient between conscious and unconscious Prime Indices (PIs)—to quantify condition-specific dissimilarities (Figure 3).

Under unconscious priming, effects were observed only when stimuli appeared in the right visual field (left hemisphere), mirroring the pattern seen in conscious conditions (Figure 3A). A significant PED difference between visual fields was detected (Figure 3A; $\Delta \mathrm{PED}_{\mathrm{uncon-con}} = 0.26 \pm 0.10$, p = 0.030), indicating that hemispheric asymmetries modulate priming differently depending on awareness. In contrast, comparisons across target stimuli and prime type revealed no significant differences (Figure 3C-F: face vs. animal; $\Delta \mathrm{PED}_{\mathrm{uncon-con}} = 0.08 \pm 0.10$, p = 0.480; image vs. word: $\Delta \mathrm{PED}_{\mathrm{uncon-con}}$ = -0.06 ± 0.10, p = 0.540).

These results indicate that unconscious priming effects are not uniformly absent but depend on specific processing pathways, with left-hemispheric dominance distinguishing conscious from unconscious processing. Unlike target type and prime type, which showed consistent effects across awareness, visual field-dependent differences highlight a neural substrate critical for recognition, providing insight into how awareness and hemispheric specialization interact in shaping priming effects.

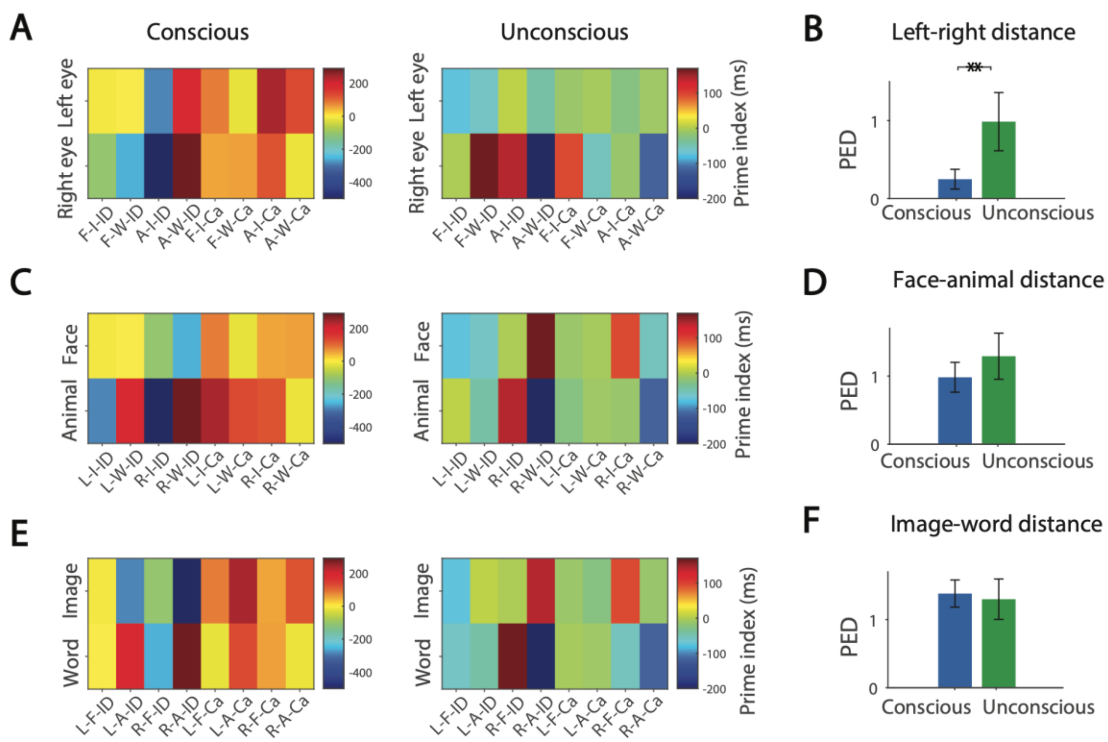

Figure 3: Priming effects across conscious and unconscious conditions
(A, C, E) Scaled color image plots compare Prime Index (PI) values between conscious and unconscious conditions across three dimensions: (A) visual field (L: left, R: right), (C) target type (F: face, A: animal), and (E) prime type (I: image, W: word), with recognition levels (ID: identity, Ca: category) nested within each. **(B, D, F)** Priming Effect Difference (PED), calculated as 1 minus the correlation coefficient between conscious and unconscious PIs, quantifies dissimilarity for each pairwise condition: (B) visual field, (D) target type, (F) prime type. error bars represent SEM.

Awareness modulates identity priming in opposite directions

To evaluate the scope and magnitude of unconscious priming, we focused on identity recognition, which involves slower processing and greater neural complexity than category recognition. We analyzed eight conditions combining prime type (image vs. word), visual field (left vs. right), and target type (face vs. animal) at the identity level, assessing their Prime Index (PI) under conscious and unconscious states (Figure 4A). A regression analysis revealed a significant negative correlation between conscious and unconscious PI values (Figure 4: r = -0.70, p = 0.026), indicating opposite effects: positive priming in conscious conditions (faster RTs) corresponded to negative priming in unconscious conditions (slower RTs), and vice versa. No such relationship emerged for category recognition (r = 0.07, p = 0.860). Mean PIs and standard errors of the mean (SEMs) across these conditions are detailed in Table 1, highlighting this divergence.

This inverse pattern at the identity level—positive conscious priming shifting to negative unconscious priming, and negative to positive—suggests distinct neural mechanisms underlie these states (Figure 4B). Inter-subject variability across conditions further underscores this dissociation, reinforcing the condition-dependent nature of priming effects on identity recognition. Each scatter plot displays the Prime Index (PI) for individual participants under the eight possible condition combinations derived from three factors: visual field (left/right), prime type (image/word), and target stimulus (face/animal). Each point represents a participant's mean PI for a given combination, with the x-axis showing conscious and the y-axis showing unconscious conditions. Deviations from the diagonal (unity line) indicate how awareness modulates the priming effect: points above the line reflect stronger priming under unconscious conditions, whereas points below the line reflect stronger priming under conscious conditions. The accompanying histograms illustrate the inter-subject distributions of PI values for each condition, showing variability and consistency across participants.

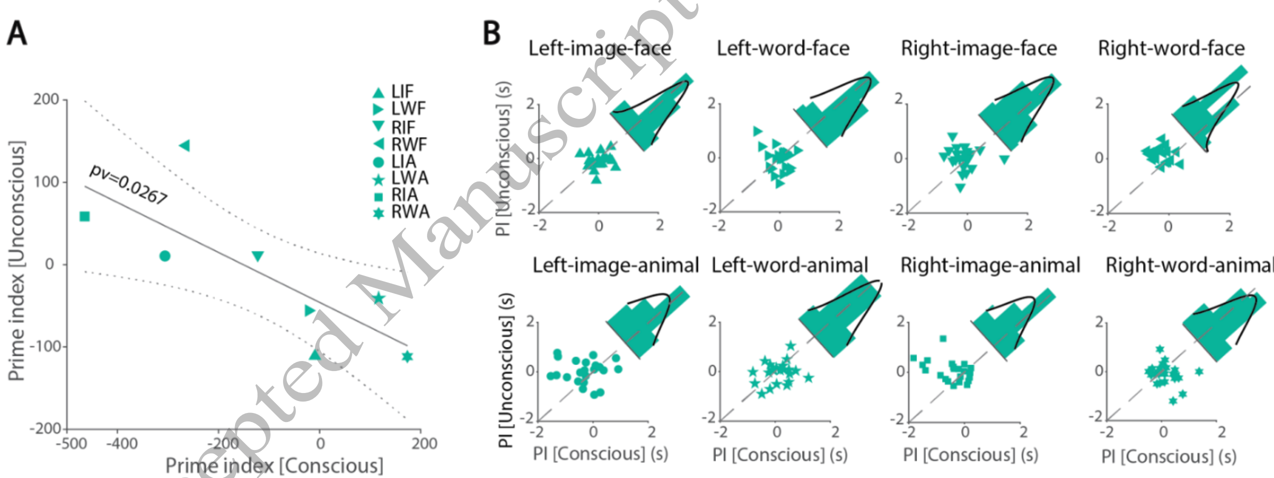

Figure 4: Divergent conscious and unconscious priming effects on identity recognition **(A)** Scatter plot of Prime Index (PI) values under conscious vs. unconscious conditions at the identity level, across eight conditions combining visual field (Left/Right), prime type (Image/Word), and target type (Face/Animal). **(B)** Scatter plots and histograms depict PI (RT difference between relevant and irrelevant primes) for all participants across the eight conditions, labeled by factor combinations (e.g., Left-Image-Face), in conscious and unconscious states. error bars represent SEM. The unit of time in the figure is second (s).

Modulation of identity recognition by visual field, prime type, and target type

We examined how prime stimuli modulate reaction times (RTs) in identity recognition trials, focusing on visual field effects. Under conscious priming, left visual field shows did not reach significance (Figure 5A, 5B, 5C, 5D), while right visual field (left hemisphere) presentation significantly influenced the Prime Index (PI) across multiple conditions: image primes with faces (Figure 5E, RIF: $\Delta PI_{con} =$ -122.3 ± 86.0 ms, p = 0.028), image primes with animals (Figure 5F, RIA: $\Delta PI_{con} =$ -464.6 ± 128.0 ms, p = 0.002), and word primes with faces (Figure 5E, RWF: $\Delta PI_{con} =$ -264.8 ± 61.0 ms, p = 0.001), showed positive priming (faster RTs), while word primes with animals (Figure 5H, RWA: $\Delta PI_{con} =$ 173.6 ± 92.5 ms, p = 0.094) trended toward negative priming (slower RTs), though non-significant. This suggests that prime type and target type shape the direction and strength of the conscious priming effect.

Table 1: Average prime index and d' (±SEM) for each condition on identity recognition

	LIF	LWF	RIF	RWF	LIA	LWA	RIA	RWA
Conscious	-9.34±63.9	-21.8±69	-122.38±86	-264.8±61	-305.9±143	116.8±104.7	-464.6±128	173.6±92.5
Unconscious	-110.9± 52	-55.75±93.7	11.68±85	144.54±56	10.5±100.8	-40.7±93	58.5±90.9	-111.6±9

On unconscious conditions, priming effects were limited to two cases: image primes with faces in the left visual field (Figure 5A, LIF: $\Delta PI_{uncon} =$ -110.9 ± 52.0 ms, p = 0.045) and word primes with faces in the right visual field (Figure 5G, RWF: $\Delta PI_{uncon} =$ 144.5 ± 56.0 ms, p = 0.028). Other conditions lacked significance (e.g., Figure 5F, RIA: $\Delta PI_{uncon} =$58.5 ± 90.9 ms, p > 0.05). Notably, word primes with faces in the right visual field showed a significant conscious-unconscious divergence (Figure 5G: RWF: $\Delta PI_{uncon-con} =$409.4 ± 87.2 ms, p = 0.002), with facilitation in conscious states and impairment in unconscious states for most participants.

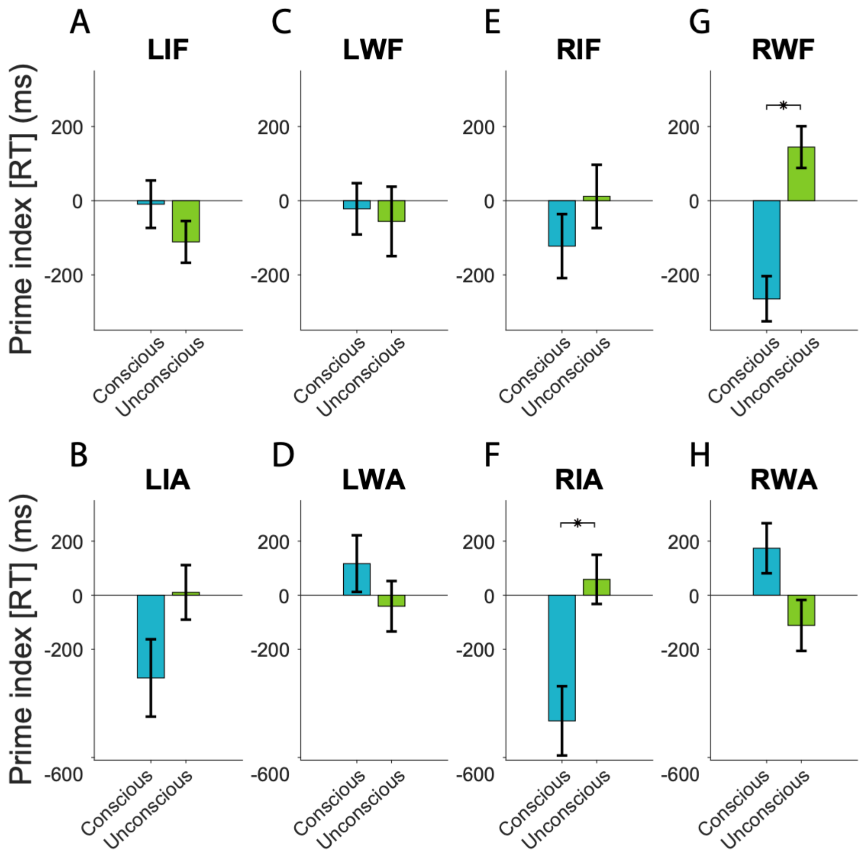

Figure 5: Conscious and unconscious priming effects on identity recognition
Bar plots depict the Prime Index (PI) across eight conditions—combinations of visual field (Right/Left), prime type (Image/Word), and target type (Face/Animal)—under conscious and unconscious states at the identity level. (A) LIF, (B) LIA, (C) LWF, (D) LWA, (E) RIF, (F) RIA, (G) RWF, (H) RWA. error bars represent SEM.

These results underscore dissociable priming effects on identity recognition across awareness states. The right visual field's consistent modulation—especially with face targets—highlights a left-hemispheric role in differentiating conscious and unconscious processing, suggesting distinct neural mechanisms underlying these effects.

Contributions of factors to prime strategies

To measure the contribution of different factors in prime strategies, we ran a non-linear regression analysis (see Methods) and computed the contribution using sensitivity scores. The sensitivity score quantifies the degree to which variations in each factor influence the response variable, with higher scores indicating greater sensitivity and a larger contribution to the prediction (Figure 6).

These scores provide a clear indication of how each factor contributes to the overall model, allowing us to assess the relative importance of each factor in shaping prime strategies.

The analysis revealed distinct contributions of different experimental factors to the prediction of the prime index, measured as the reaction time difference between the prime and the irrelevant prime. The mean sensitivity scores (± standard deviation) for each factor were as follows: laterality (0.1008±0.0541), prime type (0.2164±0.0864), target stimuli (0.1458±0.0794), awareness (0.2794±0.0895), and recognition level (0.2577±0.0739). Among these, Awareness exhibited the highest contribution, followed closely by recognition level, while laterality had the lowest contribution.

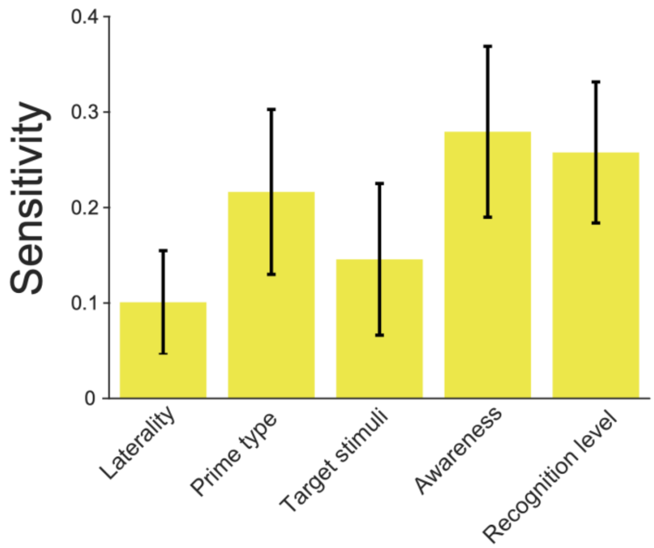

Figure 6. Feature sensitivity analysis for predicting the prime index.
This bar plot presents the contribution of different experimental factors in predicting the Prime Index using a support vector regression (SVR) model. The x-axis represents the analyzed factors: Laterality (Left/Right visual field), Prime type (Image/Word), Target stimuli (Face/Animal), Recognition level (Identity/Category), and Awareness (Conscious/Unconscious). The y-axis shows the normalized sensitivity scores, indicating the relative influence of each factor on the Prime Index. Bars represent the mean sensitivity scores across 500 bootstrap resampling iterations, with error bars denoting standard deviations. Statistical significance was assessed through p-values comparing each factor's contribution against zero and pairwise comparisons between factors, providing insights into their relative importance.

Statistical tests assessing whether each factor's contribution significantly differed from zero showed that all factors, except for Target stimuli ($p = 0.0517$; which is near significant), reached statistical significance: laterality ($p = 0.0393$), prime type ($p = 0.0101$), awareness ($p = 0.0017$), and Recognition level ($p = 0.0009$). These results indicate that most factors played a meaningful role in explaining variations in the prime index.
Pairwise comparisons between factors revealed no statistically significant differences at the conventional ($\alpha = 0.05$) level. However, some comparisons approached significance, such as the

difference between laterality and awareness (p = 0.0568) and laterality and recognition level (p = 0.0578). The remaining pairwise comparisons yielded p-values above 0.1, suggesting comparable contributions among factors.

Overall, these findings highlight the importance of awareness and recognition level in predicting the prime index, with prime type also playing a notable role. The lower contributions of laterality and target stimuli suggest a more limited influence on reaction time differences.

Discussion

The present study provides evidence for a context-dependent prime aftereffect in how conscious and unconscious priming influence visual recognition. Using a binocular rivalry paradigm (Navab kashani et al., 2025), in conscious primes, identity-level recognition improved, whereas category-level recognition suffered, while unconscious priming failed to produce such differential effects. Moreover, we noted a left hemisphere bias between conscious and unconscious conditions. This lateralization may reflect the specialization of cortical areas involved in detailed visual processing and linguistic comprehension. Notably, we noted a negative correlation between conscious and unconscious perception in identity recognition tasks, underscoring how visual perception can vary depending on the conditions within the priming paradigm.

The experimental design allows for the exploration of factors including global versus detail processing, the influence of image versus word analysis, functional hemispheric asymmetries, and the familiarity of objects. This approach is founded on the idea that distinct neural substrates in the human brain are utilized for the recognition of categories and identities.

Categorization is typically faster than identity recognition (Dehaqani et al., 2016; Rosch et al., 1976) and is mainly supported by feedforward pathways in the visual system (Lamme & Roelfsema, 2000; Mohsenzadeh et al., 2018; Serre et al., 2007). This initial feedforward sweep rapidly organizes visual features but alone does not generate awareness (Jehee et al., 2007; Scholl et al., 2014; Stienen et al., 2012; Thorpe et al., 1983). While feedforward processing underlies fast, pre-attentive, unconscious vision, recurrent processing is slower and essential for attentive vision and conscious awareness (Lamme & Roelfsema, 2000; Salin & Bullier, 1995; Schmidt et al., 2011). Recurrent connections integrate detailed information over time, enabling more complex object recognition at the identity level compared to the categorization level (Hochstein & Ahissar, 2002; Jehee et al., 2007). This sustained integration supports conscious perception and contextual interpretation (Hochstein & Ahissar, 2002; Pollen, 1999). Our findings indicate that conscious priming mainly influences recurrent, detail-oriented processing, whereas feedforward global processing is less affected by either conscious or unconscious priming. When these pathways are consciously primed, repetition accelerates identity recognition, which requires deeper analysis (Dobbins et al., 2004; Tulving & Schacter, 1990). Conversely, conscious priming of faster categorization may slow processing due to increased informational load and neural fatigue (Grill-

Spector et al., 2006). Thus, conscious awareness appears to selectively modulate feedforward and recurrent pathways, engaging distinct neural substrates for categorization and identification.

However, subliminal information that enters the brain unconsciously will have a different effect. Unconscious information cannot affect the categorization level, suggesting that the processing of categorization information in the feedforward path, which is unattended and unaware, does not allow enough time to analyze unconscious information. Conversely, the detailed processing of information that involves both forward and backward paths, depending on the conditions, allows for the utilization of unconscious information to some extent during analysis.

The literature on unconscious priming presents conflicting views, with some studies demonstrating its influence on brain processing (Dehaene et al., 1998; Vuilleumier et al., 2002; Williams et al., 2004) and behavior (Jiang et al., 2007; Stein et al., 2020; Zhou et al., 2010). However, other research emphasizes the necessity of conscious awareness for effective information processing (Amihai et al., 2011; Moradi et al., 2005b). Moradi's article illustrates that unconscious image priming with face stimuli does not impact identification processing. In his experiments, stimuli were presented to the adapting eye, considering that most people are right-eyed, which is just one specific condition. A comprehensive map of conditions is needed to better understand brain function. Additionally, in conscious states, prime stimuli were presented for 4 seconds, leading to adaptation rather than a priming aftereffect (Moradi et al., 2005). Amihai also argues that conscious awareness is required for processing gender and race, supporting our findings that these features are considered at the categorization level and their aftereffects vanish through unconscious priming (Amihai et al., 2011).

These results can be interpreted within the framework of feedforward/feedback models of perception. According to this framework, perception is guided by top-down predictions that interact with bottom-up sensory input, with prediction errors driving the updating of internal models (Friston & Kiebel, 2009). Conscious primes likely instantiate strong, feedback-driven predictions about the upcoming stimulus, which, when correct at the identity level, reduce prediction error and speed recognition. However, when the prime mismatches the target at the category level, these specific predictions may interfere with rapid grouping into broader categories, producing slower responses. In contrast, unconscious primes appear to trigger only weak feedforward activations, insufficient to generate sustained predictive feedback, which explains their lack of task-dependent influence (Kiefer & Spitzer, 2000; Kouider & Dehaene, 2007). This interpretation aligns with evidence that category-level information can be extracted rapidly through feedforward sweeps in inferior temporal cortex (Eleanor Rosch, et al., 1976; Grill-Spector et al., 2006), whereas conscious, recurrent processing is required for detailed identity-level recognition.

Although laterality effects are well documented in the literature, our analysis revealed that this factor contributed the least to predicting priming performance (Figure 6). This apparent discrepancy likely stems from the comprehensive nature of our model, in which multiple interacting variables—awareness, recognition level, prime type, and target domain—were examined simultaneously. When such interdependent factors are jointly considered, the specific influence of visual field laterality becomes partially masked, reflecting shared variance with higher-level cognitive processes rather than an absence of hemispheric asymmetry.

Several limitations should be acknowledged. First, the current study relied exclusively on behavioral measures, preventing direct inference about underlying neural mechanisms. Future research combining this paradigm with EEG or fMRI could clarify the temporal and spatial dynamics of conscious and unconscious priming. Second, our stimulus set was limited to faces and animals; expanding to other stimulus domains (e.g., tools, scenes) would enhance generalizability. Third, although Continuous Flash Suppression effectively manipulated awareness, residual variability in suppression depth across participants may have influenced unconscious effects. Finally, the relatively small sample size limits the detection of subtle interactions among factors. Addressing these limitations could strengthen the mechanistic interpretation of awareness-dependent visual processing.

In sum, our study advances current theories of visual awareness by demonstrating that conscious and unconscious priming are not simply weaker versus stronger versions of the same mechanism, but qualitatively distinct processes with different effects on recognition. Conscious awareness enables flexible, context-dependent modulation, sometimes beneficial and sometimes detrimental, reflecting the integration of sensory input. Unconscious priming, in contrast, remains limited to shallow, feedforward influences that lack such flexibility. These results not only deepen our understanding of how awareness and recognition level interact to shape perception, the functioning of visual perception circuits varies depending on the condition, emphasizing the joint influence of awareness and contextual factors on recognition processes.

Data availability

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT (OpenAI) to assist with language editing, summarization, and refinement of highlights. After using this tool, the authors reviewed and edited the content as needed and takes full responsibility for the content of the published article.

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