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Abstraction Level Exerts Reverse Effects on Conscious and Unconscious Priming

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Abstract

Objective: Understanding how the brain processes visual information with and without awareness is a key challenge.

Method: We developed a novel binocular rivalry paradigm combining Continuous Flash Suppression (CFS) with a name–picture verification task to compare identity level versus category level priming under conscious and unconscious conditions. Our fully factorial design simultaneously manipulated all potential factors (visual field laterality, prime modality, trial congruency, stimulus type, and abstraction level), a combination not previously tested. Using mixed-effects regression, we regressed out these factors and isolated the specific impact of each.

Results: Crucially, we found that only the abstraction level (basic-category vs subordinate-identity) showed a significant effect: Abstraction level processing produced opposite behavioral effects when prime stimuli were consciously perceived versus when suppressed. We confirmed this pattern with subject-wise regressions, finding a reliable reversal for the abstraction factor.

Discussions: These results highlight that conscious and unconscious vision rely on distinct representational dynamics rather than differing only in strength. Our approach – integrating all variables in one experiment and using mixed-effects GLM – provides a comprehensive test of priming influences.

Keywords: Visual Priming, Binocular Rivalry, Abstraction Level, Consciousness, Mixed Effect Regression, GLM

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1. Introduction

Visual stimuli can influence behavior even when people are unaware of them. Classic studies show that masked or suppressed words and images can speed or bias responses to subsequent targets (Jiang & He, 2006; Ortells et al., 2006; Stein et al., 2020). Neuroimaging studies suggest that subliminal information can be processed without conscious awareness (Fang & He, 2005; Jiang & He, 2006; Williams et al., 2004). However, there is debate over what information remains accessible (Amihai et al., 2011; Axelrod & Rees, 2014; Moradi et al., 2005). A level-of-categorization framework asks whether coarse, basic-level categories (e.g., “dog”) versus fine-grained, subordinate identities (e.g., “Doberman”) can be extracted unconsciously (Marsolek, 1999). For example, Amihai et al. (2010) used CFS with faces and found that superordinate attributes (face vs non-face) did not require awareness, but basic level attributes (face identity, race, gender) did (Amihai et al., 2011). Similarly, Koivisto and Rientamo reported that continuous-flash-suppressed primes facilitated superordinate categorization (animal vs non-animal) but had no effect on basic-level distinctions (horse vs other animal) unless primes were consciously seen (Koivisto & Revonsuo, 2000). Taken together, these findings suggest that unconscious priming does not reliably facilitate basic-level recognition, whereas its potential influence at the subordinate level remains less clearly established.

To probe this directly, we combined binocular rivalry/CFS with a well-controlled verification task. In our task, participants decided if a visually presented picture matched a preceding name. On “identity” trials, the name was a specific identity (e.g., “Bulldog”), and on “category” trials, a basic category (e.g., “Dog”). This design follows prior verification paradigms (Collin & Mcmullen, 2005) that carefully balance semantic levels. Critically, we presented prime stimuli (words or pictures) either at the identity or category level, and either visibly or rendered invisible by CFS. Binocular rivalry/CFS is a powerful “blinding” method: a high-contrast Mondrian mask flashed to one eye can suppress an image to the other eye for several seconds, far longer than conventional masking (Tsuchiya & Koch, 2005). Thus, CFS can keep primes subliminal while they potentially influence target processing. Unlike some CFS studies that break suppression (b-CFS), we measured priming on a separate task, following setups like Tsuchiya and Koch (2005) and Axelrod et al. (2015).

Our experiment varied all factors in mixed-effects analysis: left vs right visual field (laterality), prime modality (word vs image), trial congruency (match vs mismatch), stimulus type (face vs animals), and abstraction level (identity vs category). By doing so, we ensure that our key contrast (abstraction level) is not confounded by any other variable. We analyzed reaction time and performance with a mixed-effects General Linear Model (GLM), including random effects for subjects and items, to regress out nuisance influences. This comprehensive approach – unique in the literature – allows us to isolate the effect of abstraction level with high confidence. We then verified the GLM findings with subject-wise regression analyses.

Overall, this study addresses unresolved questions: Can category and identity primes operate without awareness? Does conscious awareness invert the priming effects? And how do various factors interact? By combining multiple manipulations in one paradigm, our aim was to provide a definitive test of these mechanisms and reveal the relative contributions of conscious vs unconscious processing across abstraction levels.

2. Method

Participants and stimuli

Twenty-two right-handed adults (mean age 35.7 years; 8 female), all with normal or corrected-to-normal vision, participated with informed consent under approved ethics. The stimulus set comprised Persian lexical items alongside grayscale depictions of four distinct entities—women, men, cats, and dogs—each presented under two recognition conditions: identity and category. Continuous Flash Suppression (CFS) with Mondrian noise (20 Hz) was used to manipulate awareness, and stimuli were luminance-matched with the SHINE Toolbox.

Procedure and design

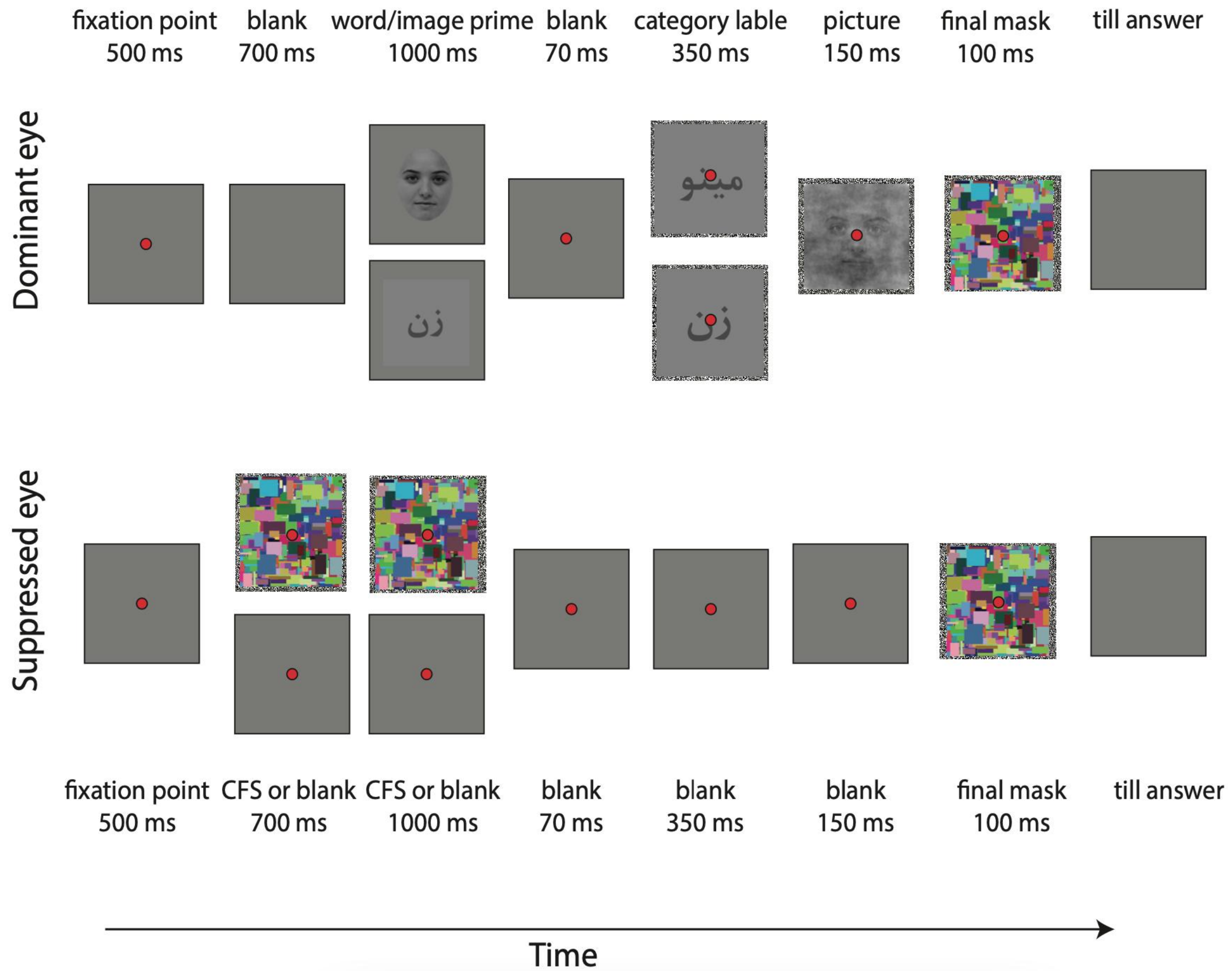
Identity and category recognition were tested using a name–picture verification task. Participants judged whether a name label matched a subsequent picture, with equal match/mismatch trials. Identity trials required subordinate-level discrimination (e.g., Minu vs. Laleh), while category trials involved basic-level judgments (e.g., woman vs. man). We designed mismatch trials such that identity-level trials had distractors from the same category, whereas category-level trials used distractors from a different category, thereby eliminating any overlap at the superordinate level. Primes were words or images, either relevant (related to the target) or irrelevant (unrelated category or identity).

Adapted from Navab et al, 2025, participants trained to >95% performance before the main task. In the experiment, primes (word or image) and targets were lateralized to visual fields, with primes suppressed by CFS in unconscious conditions. After each block, participants were briefly interviewed about the task to ensure that none of the primes had reached conscious awareness. Each trial involved fixation (500 ms), CFS/blank (1700 ms), prime (1000 ms, low contrast), a word label (350 ms), and a target picture (150 ms) masked by noise. Responses were given by keypress (match/mismatch). As presented in Figure 1, conscious primes were presented without CFS and remained visible (Navab kashani et al., 2025).

Each participant completed 768 trials, randomly drawn from the different experimental conditions. Reaction time and performance were recorded for every trial, and correct trials with response times longer than 6,000 ms or shorter than 50 ms were excluded, resulting in the removal of less than 5% of all trials.

Figure 1. ***Experimental paradigm and trial sequence***

One eye viewed rapidly changing colored Mondrian masks (CFS), while the other eye saw low-contrast primes (words or images, identity or category). A central fixation, followed by 1000 ms prime (suppressed in unconscious trials, visible in conscious trials), then a name label, then a target picture. Participants judged match vs mismatch at the indicated level (the figure adopted from Navab kashani et al., 2025).



Regression model

To examine how task factors influenced behavioral responses, we used generalized linear mixed-effects models (GLMMs). Mixed-effects models allow us to account for both fixed effects of experimental factors and random effects due to inter-subject variability, capturing the hierarchical structure of the data (trials nested within participants).

For each response type Y (RT or Performance), the model is:

$$g(E[Y_{ij}]) = \beta_0 + \sum_{k=1}^{p} \beta_k X_{ijk} + u_j$$

Where:

- i indexes trials, j indexes subjects.
- X_{ijk} are the fixed-effect predictors for trial i in subject j:
    - Laterality

  - Prime modality
  - Trial congruency
  - Stimulus type
  - Abstraction level

- β_k is the fixed-effect coefficients represent the contribution of each factor.
- u_j is the random intercept for subject j, assumed $u_j \sim \mathrm{N}(0, \sigma^2)$, capturing subject-specific deviations from the population mean.
- $g(0)$ is the link function:
  - Gamma-log link for reaction time $Y_{ij} = RT_{ij}$ to model skewed positive RTs.
  - Binomial-logit link for binary performance $Y_{ij} = Per_{ij}$, representing success/failure.

Subject-wise regression

To capture individual differences in factor sensitivity, we also ran subject-wise regressions. Each subject's trial data was fit separately:

$$g\big(E[Y_j]\big) = \beta_0^{(s)} + \sum_{k=1}^{p} \beta_k^{(s)} X_{ik}$$

Where $\beta_k^{(s)}$ is the effect of factor k for subject s. This produces a distribution of coefficients across participants, which was subsequently used for statistical inference.

Bootstrap procedure

To estimate confidence intervals (CIs) and p-values for model coefficients and derived indices, we applied a subject-level bootstrap:

1. Resample subjects with replacement.
2. For each bootstrap sample, fit the GLMM or subject-wise GLM.
3. Extract coefficients β_k for each factor.
4. Repeat B=1000 times to generate bootstrap distributions of coefficients.

This approach preserves the within-subject correlation structure while estimating variability across participants.

Effect size estimation

The effect sizes were estimated using a *Cohen's d–like* statistic (Wilcox, 2019), defined as the absolute difference between group means divided by the pooled standard deviation:

$$dp = \frac{|\mu_1 - \mu_2|}{\mathrm{S}_p}, \quad \mathrm{S}_p = \sqrt{\frac{\mathrm{var}_1 + \mathrm{var}_2}{2}}$$

Here, S_p denotes the estimation of the pooled standard deviation, which reflects the within-group dispersion of the data and is equivalent to the square root of the mean of the group variances. In cases where bootstrap resampling was applied, S_p was computed as the variance of the bootstrap samples. For analyses involving the Wilcoxon signed-rank test, with independent samples, we estimated the variance of the sample mean using the formula $\frac{\mathrm{var}}{\sqrt{N}}$, where var represents the estimated population variance.

Prime index

For each factor, we defined a Prime Index (PI) to quantify the influence of the prime type:

$$PI = \frac{\beta_{relevant} - \beta_{irelevant}}{\beta_{relevant} + \beta_{irelevant} + \varepsilon}$$

Where ε is a small constant to prevent division by zero. This index was computed per subject and per consciousness condition**.** Bootstrap samples were used to estimate 95% confidence intervals and p-values for the comparison between conscious and unconscious conditions.

Statistical analysis

- Comparison between conscious and unconscious conditions:
  - For each factor, we computed paired differences in PI across subjects.
  - Bootstrap p-values were estimated as:

$$p = 2 * \min\left(pr(diff > 0), (pr(diff < 0)\right)$$

All analyses were implemented in MATLAB R2025a using *fitglme* for mixed-effects models and custom scripts for bootstrap and plotting.

3. Results

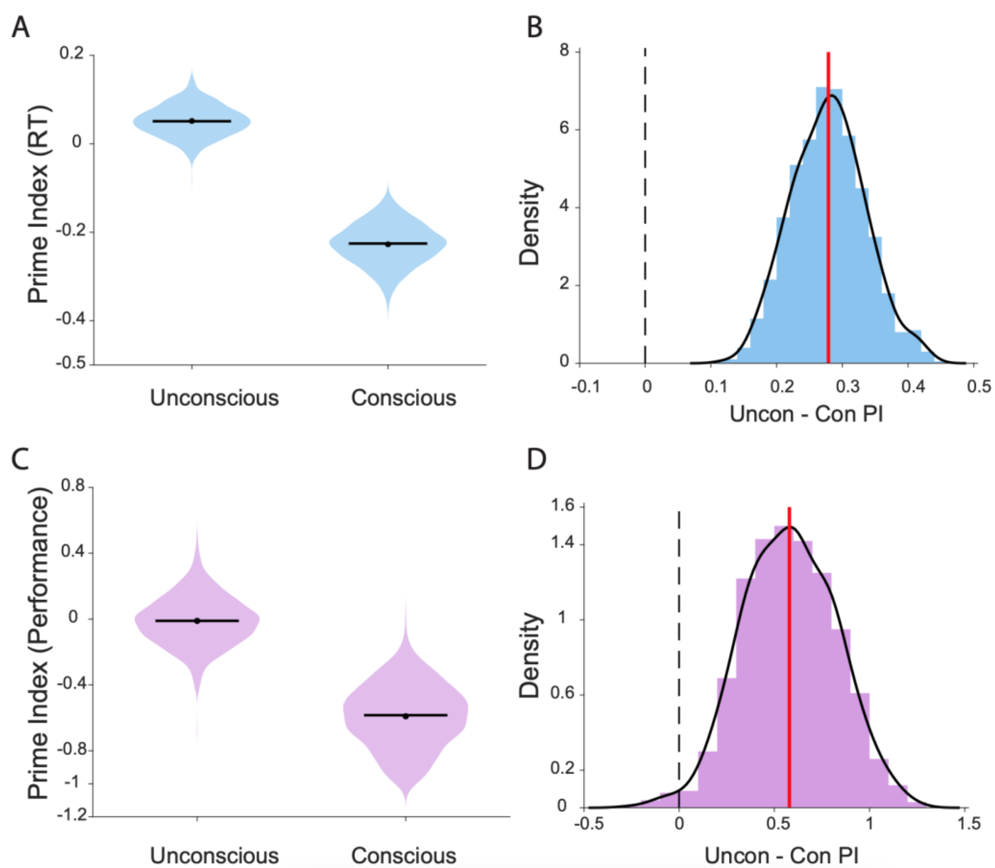
The mixed-effects regression analysis revealed that only the prime's level of abstraction (basic-level category vs. specific identity) showed a significant difference between conscious and unconscious trials. In other words, awareness modulated abstraction level priming in an opposite manner, whereas no other factor (prime modality, visual field, trial congruency, or Stimulus type) produced a reliable priming difference across awareness conditions. Abstraction level processing elicited opposite behavioral effects when visible versus suppressed, while other factors had similar, negligible effects regardless of awareness.

Mixed-effects analysis priming effects

At the group level, the mixed-effects regression analyses revealed a reliable interaction between consciousness and the level of abstraction. Specifically, abstraction level processing showed opposite effects depending on whether primes were consciously perceived or suppressed from awareness. By comparison, other factors showed no meaningful modulation by awareness; their priming indices remained close to zero in both conscious and unconscious trials, indicating negligible influence on performance.

For reaction times, this pattern was statistically robust. Abstraction level processing with subliminal prime yielded a mean prime index of 0.052 (Figure 2A; 95% CI [–0.017, 0.117]), whereas in the conscious condition, the mean dropped to –0.227 (Figure 2A; 95% CI [–0.321, –0.143]), a difference that was highly significant ($p = .001$, pd = 6.8782). Figure 2B plots the within-subject difference (Unconscious – Conscious) of the prime index for RT. The distribution is centered above zero, indicating faster RTs when prime stimuli were suppressed versus seen. As shown in Table 1, no other factor—laterality (left vs. right visual field of the prime), prime modality (word vs. image prime), trial congruency (name-picture match vs. mismatch), or stimulus type (faces vs. animals) —reached significance (all $p > .20$).

Figure 2. ***Prime-index effects for reaction time and performance***
(A) Reaction-time prime index for abstraction level trials, plotted as violin plots for unconscious (CFS) versus conscious conditions. Abstraction level primes showed significant opposite effects. (B) Distribution of Prime index difference (Unconscious minus Conscious) in the RT prime index. (C–D) Analogous plots for performance: (C) prime index in performance, and (D) distribution of differences.



Performance measures showed a similar trend, though the effects were weaker. Abstraction level again produced more negative indices when consciously primed (Figure 2C; M = –0.590, 95% CI [–0.954, –0.243]) compared to when unconscious (Figure 2C; M = –0.011, 95% CI [–0.304, 0.287]), a significant difference ($p = .026$, pd = 3.3617). By contrast, as shown in Table 2, none of the other experimental factors were significant (all $p > .15$). Again, the abstraction level difference yields a positive shift for unconscious vs conscious (Figure 2D).

Together, these group-level results indicate that awareness modulates prime index in the abstraction level, reversing its behavioral impact, whereas all other factors remain unaffected.

Table 1*: prime index for all factors using reaction time*

Factor	Mean_Uncon	CI_Uncon_low	CI_Uncon_high	Mean_Con	CI_Con_low	CI_Con_high	p_value
Laterality	0.315	-0.716	0.957	-0.178	-0.952	0.818	0.466
Prime modality	-0.032	-0.91	0.899	0.231	-0.76	0.938	0.71
Congruency	0.055	-0.136	0.24	0.217	0.019	0.394	0.228
Stimulus type	0.019	-0.181	0.214	0.018	-0.15	0.186	0.986
Abstraction level	0.052	-0.017	0.117	-0.227	-0.321	-0.143	0.001

Table 2: prime index for all factors using performance

Factor	Mean_Uncon	CI_Uncon_low	CI_Uncon_high	Mean_Con	CI_Con_low	CI_Con_high	p_value
Laterality	-0.122	-0.942	0.915	0.103	-0.893	0.931	0.742
Prime modality	-0.024	-0.694	0.573	0.577	0.019	0.98	0.156
Congruency	0.099	-0.355	0.58	0.372	-0.176	0.94	0.446
Stimulus type	0.033	-0.096	0.155	0.042	-0.06	0.142	0.902
Abstraction level	-0.011	-0.304	0.287	-0.59	-0.954	-0.243	0.026

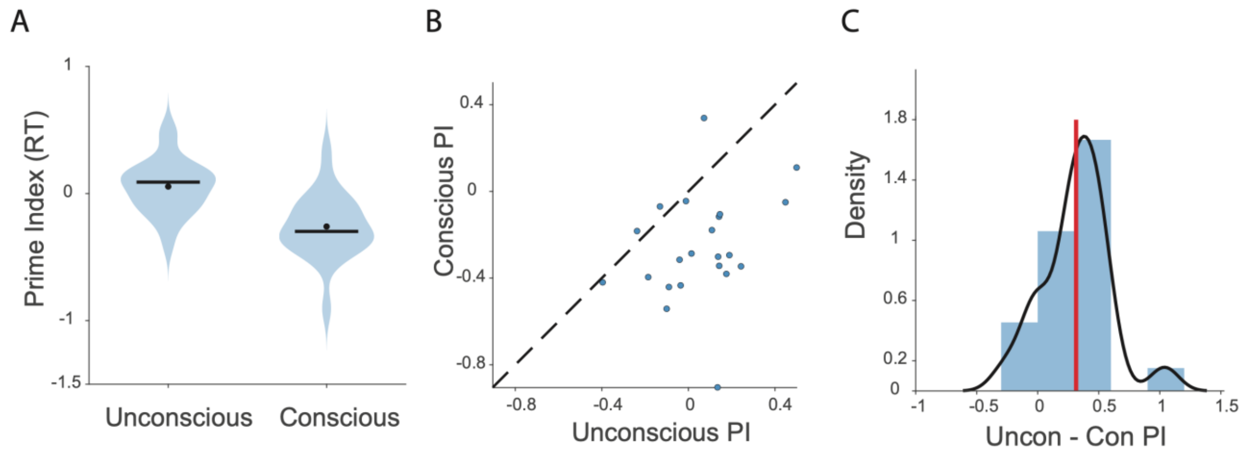
Subject level analyses

Subject-wise regression confirmed that the awareness by abstraction interaction observed at the mixed-effects analysis was also robust within individuals. Across participants, reaction time priming indices for abstraction level processing shifted from positive values in the unconscious condition (Figure 3A; M = 0.06, SD = 0.04) to negative values in the conscious condition (Figure 3A; M = –0.26, SD = 0.05). A Wilcoxon signed-rank test confirmed the reliability of this reversal (Figure 3A; p = .0003, pd = 1.3897). No other factor exhibited a significant difference across awareness conditions at the subject level; all other comparisons produced nonsignificant results (Table 3; all p > .27).

Performance results at the subject level did not reveal reliable awareness effects. The mean priming index for abstraction level was slightly negative in both unconscious (Table 4; M = –0.20, SD = 0.10) and conscious (Table 4; M = –0.11, SD = 0.11) conditions, and this difference was not significant (p = .59). All other factors showed similarly null effects (Table 4; Wilcoxon tests, p > .40).

Figure 3. *Subject level analysis of RT priming*

(A) Violin plots of each subject's mean RT prime index by condition (identity vs category; conscious vs unconscious), summarizing the same data as Figure 2A but averaged per subject. (B) Scatterplot of individual subjects' conscious versus unconscious prime indices. Points falling off the diagonal indicate an awareness effect. The dashed line marks zero difference. (C) Histogram of subject-wise differences (Unconscious minus Conscious) in RT prime index, illustrating the consistent positive shift for abstraction level processing.



Individual level analyses further supported the group findings, showing that the prime index of abstraction level in reaction times reversed with awareness. No such modulation emerged for any other task factor. Performance outcomes, by contrast, were largely unaffected by awareness, with all factors' prime indexes yielding minimal differences across conditions.

Table 3: ***Subject-wise analysis PI for all factors using reaction time***

Factor	Mean_Uncon	Std_Uncon	Mean_Con	Std_Con	p_Wilcoxon
Laterality	-0.13	0.12	0.08	0.12	0.276772
Prime modality	-0.04	0.09	0	0.12	0.883846
Congruency	0.03	0.09	0.11	0.12	0.708884
Stimulus type	0.17	0.08	-0.03	0.06	0.354825
Abstraction level	0.06	0.04	-0.26	0.05	0.000295

Table 4: ***subject wise analysis PI for all factor using performance***

Factor	Mean_Uncon	Std_Uncon	Mean_Con	Std_Con	p_Wilcoxon
Laterality	-0.21	0.1	-0.05	0.11	0.445498
Prime modality	-0.03	0.1	0.05	0.1	0.832866
Congruency	0.03	0.12	0.1	0.09	0.733187
Stimulus type	-0.02	0.1	-0.02	0.07	0.637818
Abstraction level	-0.2	0.1	-0.11	0.11	0.592177

Taken together, the results converge on a single, robust effect: conscious and unconscious priming modulate abstraction level processing in opposite directions. All other factors examined, showed no reliable influence under either condition. This selective interaction underscores the unique role of the abstraction level in shaping how conscious and unconscious visual processing affect behavior.

4. Discussion

The present study provides clear evidence that conscious awareness fundamentally alters the way abstraction level information influences visual priming. Across both mixed-effects and subject level analyses, prime indexes exhibited opposite effects in abstraction level depending on awareness. No other experimental factors—including visual field laterality, prime modality, congruency, or stimulus type—produced reliable differences across conscious and unconscious trials. This pattern highlights a selective awareness-by-abstraction interaction that dissociates the contributions of conscious and unconscious visual processing.

Our findings extend prior debates on the scope of unconscious visual processing. Earlier studies have reported inconsistent results regarding whether categorical or identity-level information can be extracted without awareness (Amihai et al., 2011; Koivisto & Revonsuo, 2000; Stein et al., 2020). The present study clarifies these discrepancies by showing that awareness priming preferentially engages abstraction level processing. This is consistent with accounts of unconscious vision as biased toward coarse, global information (Hesselmann et al., 2016; Marsolek, 1999). Importantly, by including both category- and identity-level primes in the same factorial design and analyzing them with mixed-effects regression, our study provides a direct within-experiment comparison that previous work often lacked.

A striking aspect of our results is the reversal of the prime index in the abstraction level with awareness. This suggests that conscious awareness not only amplifies information processing but also qualitatively characterizes how the priming strategy is affected by the abstraction level.

At the neural level, our results resonate with evidence that CFS disproportionately disrupts processing of object details while sparing some coarse categorical information (Amihai et al., 2011; Moradi et al., 2005; Toosi et al., 2025; Tsuchiya & Koch, 2005). Future neuroimaging work could test these possibilities by examining whether awareness modulates the balance of fine versus global contributions to abstraction processing.

Beyond the theoretical implications, the methodological design of this study makes a distinct contribution. By integrating multiple potential confounds—prime modality, laterality, congruency, and stimulus type—into a single factorial design and statistically controlling them with generalized linear mixed-effects models, we isolated the unique contribution of abstraction level. Prior unconscious priming studies often manipulated one or two variables in isolation, leaving open the possibility of confounding effects.

Our subject-wise regression confirms that the abstraction level effect is reliable within individuals, not just at the mixed-effects analysis. This strengthens the conclusion that conscious awareness qualitatively changes priming for abstraction level information.

In summary, this study demonstrates that conscious and unconscious priming diverge most strongly in their treatment of the abstraction level. This awareness-dependent reversal highlights a fundamental difference in representational content between conscious and unconscious perception and underscores the value of integrated, factorial approaches for probing the architecture of visual processing.

Data Availability and Supplementary Data

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 take full responsibility for the content of the published article.

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