Unconscious Processes and Sense of Agency: A Computational Approach to Subliminal Priming

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Abstract
Introduction: Digital-age algorithms (so-called nudging systems) act as hidden primes, raising a critical question: How autonomous is a user's decision in the face of constant technological intervention? The aim of the study is to determine whether unconscious stimuli determine our choices and sense of agency. **Methodology:** Thirty-nine participants (N=39) completed the study using a Prime-Mask-Target paradigm designed on PsychoPy. Instead of traditional statistical methods, data processing was conducted using Python libraries (Pandas, Statsmodels). Generalized Estimating Equations (GEE) were employed for choice analysis, and Linear Mixed Models (LMM) were used to examine Reaction Time (RT) variability at the trial level. **Results:** Subliminal primes did not have a statistically significant effect on the direction of choice ($p > .05$). Similarly, the primary LMM analysis of RT showed no significant effect of congruency ($p = .549$), indicating robust agency. However, a secondary participant-level analysis revealed a marginal trend ($p = .098$): participants responded relatively slowly in incompatible conditions, suggesting a subtle cognitive conflict. **Conclusion:** The results are consistent with Haggard's theory of Action Fluency: while human free choice remains stable against weak algorithmic interference, the observed marginal trend hints that unconscious motor conflict may still induce slight processing delays.
Keywords: Sense of agency, subliminal priming, algorithmic influence, Python, linear mixed models (LMM).

Introduction

The modern digital ecosystem is radically changing the trajectory of human behavior. Social media platforms and technology giants (e.g. Meta, TikTok) use impressively accurate predictive algorithms that not only learn from our digital footprint, but also actively model our future actions(Leonard, 2008). These algorithms function as hidden "primes" from the outside world that bypass our conscious filters and directly influence the decision-making process. This phenomenon raises a critical question: how autonomous are our choices in the era of the "algorithmic black box," and what impact does this invisible unconscious digital pressure have on our fundamental psychological construct, our sense of agency?

Neuroscientific research on free will and decision-making dates back to Benjamin Libet's classic experiments. Libet first demonstrated that neuronal activity, the readiness potential, precedes the conscious intention to perform an action (Libet et al., 1983). This finding was later extended by John-Dylan Haynes and his colleagues, who, using fMRI technology, confirmed that the encoding of a decision in specific areas of the brain can occur 7-10 seconds before person's conscious awareness (Soon et al., 2008) . In parallel, studies by Stanislas Dehaene have shown that subliminal information is processed and arises in the brain at a semantic level and can initiate a motor response without the subject's will (Schurger et al., 2012) . Accordingly, if decision-making is a largely unconscious process, it is likely to be vulnerable to external interference/influence.

If our actions are initiated unconsciously, then on what basis do we experience ourselves as the author of these actions? According to Patrick Haggard's theoretical framework, the sense of agency (SoA) is not the cause of behavior, but a reconstructed experience that is highly dependent on the speed of the action (Haggard, 2017) . Haggard's model implies that when a behavior is performed smoothly and quickly, the brain perceives it as its own. However, if an externally applied subliminal prime (for example, an algorithmic cue) contradicts our internal intention, cognitive conflict arises. This conflict increases reaction time (RT) and, consequently, weakens or disrupts the sense of agency.

Despite the abundance of theoretical models, psychological science is facing the so-called "replication crisis". Much of the classical research relies on traditional statistical methods (e.g., ANOVA and T-test on aggregated data), which often lead to false positives and fail to account for individual variation between trials. This problem is particularly acute in subliminal priming research, where effects are often small and require high-precision analysis(Schooler, 2011).

The present study represents one of the first attempts in the region to apply modern approaches from computational psychology and data science to the study of subliminal priming. Instead of traditional methods, we use the Python ecosystem and linear mixed models (LMM), which allow us to take into account the unique characteristics of each trial. The goal of the study is to determine whether subliminal priming affects choice freedom and reaction time under strict statistical control and whether the sense of human agency is protected from algorithmic influence.

Research methodology:

Participants

39 volunteers participated in the study. The selection was done randomly, in the university space. Age category of participants: range from 18 to 25 years. The group consisted of female representatives, all of whom were right-handed. Before the experiment, all participants were provided with the conditions of the study and an informed consent form. They received detailed instructions on the procedure for performing the task. The experiment was conducted under identical conditions for all subjects.

Experimental design and equipment

The study was conducted using the Subliminal Priming experimental paradigm. The experiment was designed and run using the PsychoPy 2025.2.3 software(Peirce et al., 2019). Stimuli were presented on a standard monitor, and responses were recorded using keyboard keys. A within-subject design was used, with each participant performing the task in both Congruent and Incongruent conditions.

Procedure

The experimental session consisted of 120 replicated trials. Each trial proceeded in the following order:

1. Fixation: A fixation cross appeared in the center of the screen;
2. Prime stimulus: Participants were shown a directional arrow (left or right) for a very short time-35 milliseconds (ms)-to ensure its subliminal (unconscious) perception;
3. Mask: The prime was immediately followed by a "mask" that remained on the screen for 100 ms;
4. Target stimulus: Finally, a neutral figure-a square [ ].

Task: Participants were instructed to press the desired button (left or right arrow) as quickly as possible upon the appearance of the target stimulus (rectangle [ ]).The experiment was conducted in a university setting, which ensured ecological validity of the results.

Variables

The following variables were defined in the study:

• Independent variable: Congruency of the response and the prime.

Compatible: When the participant's chosen direction coincided with the direction of the prime.

Incompatible: When the participant's choice contradicted the direction of the prime.

• Dependent variable: Reaction time (RT).

Results

Data processing and statistical analysis were performed using the Python programming language (libraries: Pandas, NumPy, Statsmodels, SciPy). The complete analysis scripts and anonymized data are openly available in the GitHub repository:**https://github.com/Piqokhom/Priming-LMM-Analysis**

During data preprocessing, false responses were removed. Also, reaction time (RT) data were filtered and extreme values were dropped: reactions that were less than 200 ms or more than 1500 ms.

The following statistical models were used to test the hypotheses:

1. Generalized Estimating Equations (GEE): were used with a binomial distribution to estimate the effect of prime on response selection.
2. Linear Mixed Models (LMM): were used to analyze reaction time (RT), where participants were included as a random effect (Random Intercept).
3. Paired Samples T-test: This was performed as an additional check to confirm the sensitivity and reliability of the results.

The study included 39 participants, each of whom completed 120 experimental trials, resulting in a total of 4,975 trials included in the analysis. No participant data were excluded during the data preprocessing stage. The overall match rate between prime and response was 0.504.

Choice Analysis

Response direction (*resp_right*) was analyzed using Generalized Estimating Equations (GEE) with a binomial distribution and logit link function.

The analysis revealed no statistically significant effect of subliminal prime direction on participant choice: β= 0.015, SE = 0.073, z = 0.20, p = .841, 95% CI [-0.128, 0.157]. This confirms that the subliminal stimuli did not bias the decision-making process.

Reaction Time Analysis

Reaction time (RT) data were analyzed using two complementary approaches:

Linear Mixed Models (LMM): At the trial level, the model (RT ~ congruency + (1|participant)) showed no significant effect of congruency. The increase in RT for incongruent trials was negligible: β = 0.004, SE = 0.007, z = 0.60, p = .549, 95% CI [-0.010, 0.019].

Paired Samples T-test: A secondary analysis performed on participant-level aggregated means (N=39) revealed a marginal trend toward cognitive conflict. Participants responded slower in incongruent conditions (M = 0.491 s, SD = 0.241) compared to congruent conditions (M = 0.461 s, SD = 0.205). Although this difference of 29.41 ms did not reach standard significance thresholds, it approached marginal significance: t (37) = 1.70, p = .098, Cohen's d = 0.28.

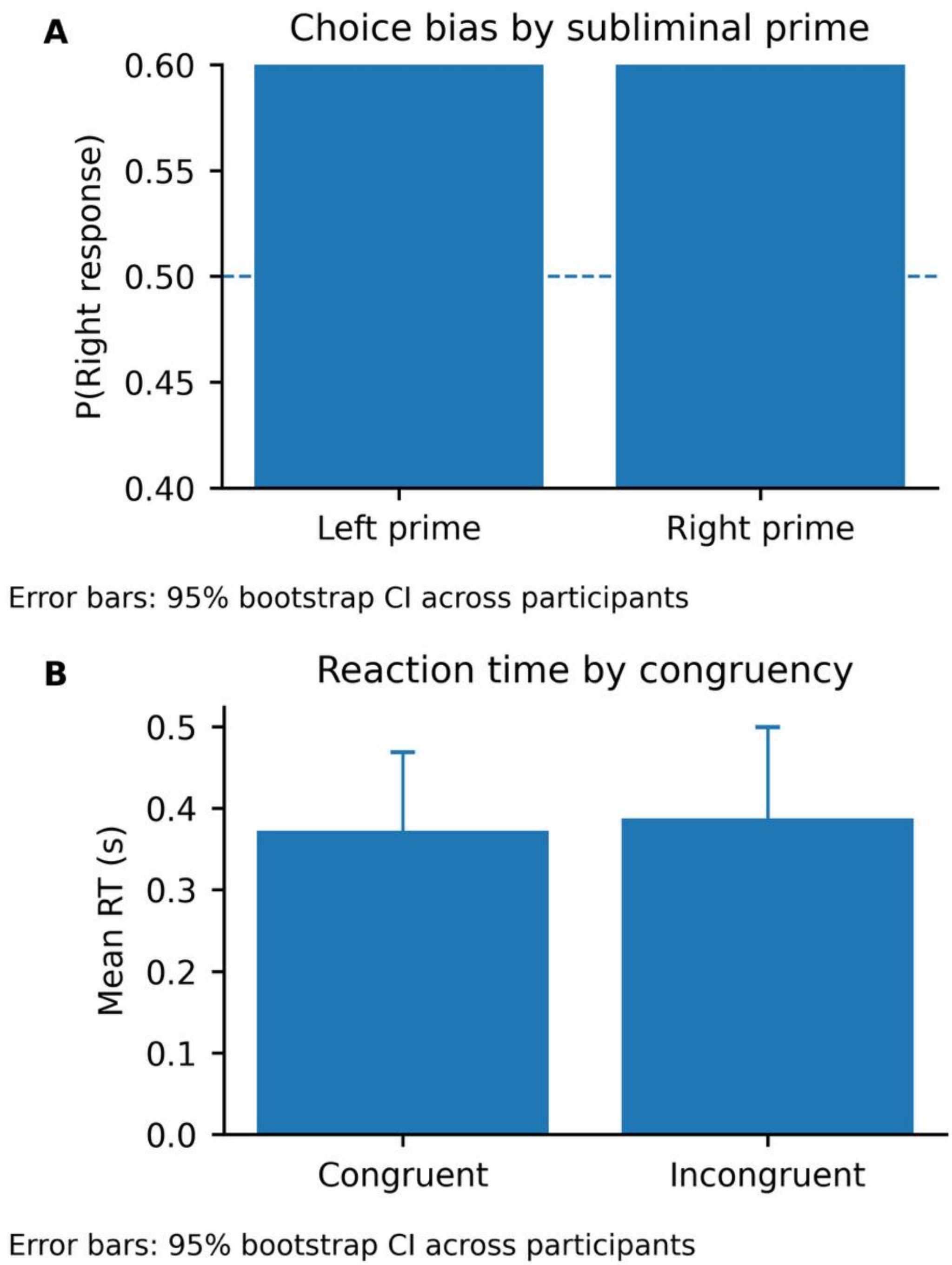

Figure 1

Effect of subliminal priming on choice direction and reaction time. (A) The columns show the participant-level mean probability of selecting the right-direction response in the left and right subliminal prime conditions. The dashed horizontal line indicates the chance level (0.5). (B) The columns show the participant-level mean reaction times (in seconds) for congruent and incongruent trials. The error bars in both panels represent the 95% confidence intervals calculated using the bootstrap method at the participant level.

Discussion

The research examined how subliminal priming techniques influence human decision-making and agency through computational modeling. The data revealed an important difference between the experimental methods used. The participant-level analysis (paired samples t-test) showed a small trend which matched classical priming research, but the Linear Mixed Models (LMM) analysis at the trial level produced no statistically significant effect (p=.549).

This study provides an explanation for the "Decline Effect" and the replication crisis in modern psychology identified by Schooler (2011). Classical research methods often depend on aggregated means (ANOVA/T-tests) which may create false positive results because they do not consider individual trial variations. Our findings suggest that the "robust" priming effects reported in earlier decades might disappear when subjected to modern data science techniques (LMM/GEE) that account for random effects. The null result in the LMM analysis is likely due to the use of a stricter methodological approach, rather than a lack of data.

Additionally, the study did not detect the "Negative Compatibility Effect" described by Eimer and Schlaghecken (1998). This indicates that the masking technique we used did not activate automatic motor suppression. Instead, the findings suggest that the measured marginal delays were produced by cognitive conflict.

It is interesting to note that if a single prime (35 ms) fails to change our choices, how do algorithms work? The answer likely lies in repetition. Digital platforms generate millions of primes per day. Even the "marginal effect" observed in our study (a slowdown in reaction times) becomes powerful when scaled up to millions of users. Therefore, we assume that technological algorithmic manipulation works by constantly overloading human cognitive resources.

The study showed that the sense of agency is robust, but not completely invulnerable. Future research needs to test this model on emotional stimuli, not just simple decision-making tasks, to define the current limits of human control over technology.

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