Is Conscious Awareness A Prerequisite to Sense of Agency?

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Abstract

This project investigates whether sense of agency can occur without consciousness using CFS and intentional binding effect. A preliminary analysis based on t-test shows that the hypothses has been rejected and that intentional binding may not be an effective way to test sense of agency. However, as the desired number of participants has not been reached, results may be subject to change.

Keywords: Consciousness, Sense of Agency, Awareness, Cognition, CFS, Intentional Binding

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Table of contents

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What exactly is the relationship between self and consciousness? Are they developments that proceed in parallel, or do they follow a specific sequence? Or, could it be that both are merely illusions crafted by the human brain?

Philosophers incline to hold the illusionist view, which argues that self-awareness is no more than a mental construction—an experience constructed as humans try to make sense of the world and develop a concept of self (Metzinger, 2004). According to this view, the self is a product of consciousness, a cognitive tool that serves to help us interpret our surroundings. But with recent advances in neuroscience, this functionalist perspective has encountered challenges, especially regarding the question of whether self-experience might have a genuine neural basis (Dehaene, 2014; A. K. Seth & Tsakiris, 2018; Tononi et al., 2016)

Neuroscientific research has suggested that self-experience may not be simply a construct of consciousness, but rather something embedded in specific neural activity (Blanke & Metzinger, 2009). This development has led scholars to reconsider the relationship between self and consciousness, as well as their potential evolutionary paths.

In response, two main perspectives have emerged: illusionist theory and independence theory. Illusion theory maintains that the self is merely a conceptual framework that humans created to understand the world; while it may be supported by certain neural mechanisms, these mechanisms are insufficient to provide a solid, physical basis for the self (A. Seth, 2021; Wegner & Wheatley, 1999). On the other hand, independence theory suggests that the sense of self can operate even without conscious awareness, functioning as a fundamental biological process rather than an extension of consciousness (Deacon & García-Valdecasas, 2023).

To explore these views, a range of experimental and theoretical studies were conducted. Libet (1985)'s readiness potential study stands as a foundational example in support of illusion theory. Libet's work revealed that the brain initiates a readiness potential—a neural precursor to action—before an individual consciously decides to act (Libet, 1985). This finding opened the door to debates about free will and self-attribution, reinforcing the idea that the self may simply be a retrospective attribution. Nevertheless, Libet's study is still in debate, especially regarding whether neural activity alone represents genuine self-experience and whether unconscious processes of self-attribution might exist (Moore et al., 2010; Neafsey, 2021).

Wegner and Wheatley (1999)'s Illusion of Thought-Action theory further strengthens the illusionist stance. They proposed that the feeling of control over one's actions often comes as a retrospective attribution, largely influenced by external cues and expectations (Wegner & Wheatley, 1999).

In contrast, research supporting independence theory explored the continuity of self-experience across conscious and unconscious states. Tsakiris and Haggard (2005)'s rubber hand illusion experiment demonstrated how self-attribution can be both flexible and automatic. This effect highlights how self-experience and bodily perception interact, suggesting that self-awareness might not rely entirely on conscious construction but could have a deeper neural basis, potentially independent of conscious oversight.

To further illustrate the underlying assumptions between the Illusion Theory and Independence Theory, think about an experience where you are absent-mindedly cutting vegetables and accidentally cut your finger. Seeing the cut, you immediately feel 'I caused this,' even though you may not have been consciously aware of when it happened. Illusion theory assumes that consciousness precedes the self, hence would interpret this as a post-hoc attribution created by consciousness, while independence theory suggests that, even without being conscious of the entire process, your body's underlying mechanisms would automatically attribute the action to self.

The implications behind these differing explanations are worth noting. If the self is merely a construct of consciousness, then mental health conditions like dissociative identity disorder or post-traumatic stress disorder (PTSD) could be seen as misconstructions by consciousness, where the focus of treatment would rely on building a healthier self-concept to help patients integrate their sense of self (Gallagher, 2000). However, if the self can exist at an unconscious level, then it may be that deeper, automatic mechanisms of self-attribution are at work in such disorders

(Gallagher, 2000).

Literature Gap and Research Question

While previous research has provided in-depth insights into the relationship between self and consciousness, studies directly investigating whether the sense of self can exist without conscious awareness is lacking.

One promising effect for investigating this topic is Intentional Binding (Haggard et al., 2002; Ruess et al., 2018), which occurs when people perceive the time interval between their action and its outcome as shorter, reflecting a sense of agency or causation. For instance, if a person presses a button and a circle appears after 0.5 seconds, they may feel their action caused the circle to appear instantly, with no time gap. When people feel agency, they tend to perceive this interval as shorter.

Utilizing this effect, we aim to investigate whether participants can experience a sense of agency (SoA)—indicated by a perceived shortening of time between action and outcome (intentional binding)—when the outcome of their action is masked from conscious awareness?

Hypotheses

Hypothesis 1: Positive Control

Hypothesis 1 serves as the foundational hypothesis, verifying that intentional binding can reliably occur under conscious conditions:

If, in the unmasked operant condition (where participants can consciously see the target stimulus), participants perceive their button press time as closer to the outcome time compared to the unmasked baseline condition (where no target stimulus appears), this would confirm that the experimental design successfully elicits the intentional binding effect, indicating a sense of agency when the outcome is consciously perceived [1].

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[1] If Hypothesis 1 is not supported, the results from Hypothesis 2 would be inconclusive, as we would lack evidence in the design's ability to measure SoA.

Hypothesis 2: Unconscious Conditions

If in the masked operant condition (where the target is suppressed from awareness), participants still perceive a time shortening, then this indicates that SoA occurs even without conscious perception.

Method

Design

This cross-sectional study uses Continuous Flash Suppression (CFS; Pournaghdali & Schwartz, 2020), a technique to mask visual stimuli from conscious awareness, to examine whether people can feel a sense of agency without consciously seeing an outcome.

Ethical Approval

The Social and Behavioral Sciences Institutional Review Board at the University of Chicago has approved this study (IRB23-1353). Informed consent will be obtained from all participants before the experiment, and they will be informed of their right to withdraw at any time. Participants will receive 1.5 course credits for participation.

Participants

Eighty undergraduate University of Chicago students with normal color vision will be recruited to allow detection of medium effect sizes with a power of 0.80 assuming an effect size of $d = 0.5$ and a significance level of 0.01. Participants will be asked about their age, biological sex and handedness.

Procedure

The experiment comprises five within-subject blocks, as follows:

1. Calibration Block: The purpose of this block is to determine the visual contrast threshold for each participant to ensure the target stimulus is effectively suppressed from conscious awareness. Participants will be required to wear red-blue anaglyph glasses. The left eye sees rapidly changing red-colored masks (10 Hz), and the right eye sees a low-contrast blue circle. In 100 trials, a blue circle appears in a random corner of the masked area between 0.25 and

1.75 seconds after the mask onset. Participants indicate which side of the screen they think the blue circle appeared on.

2. Baseline-Masked Block: The CFS masks are presented in the middle of a rotating on-screen clock, with participants still wearing red-blue glasses. Participants will be required to press the space bar at a moment of their choosing, stopping the CFS mask 1-2 seconds later. The clock stops, and after a delay, the clock hand reappears at a random position. Participants then adjust the clock hand to where they believe it was at the time of their button press. For additional check, participants will be asked after each trial if they saw a blue circle; this serves to confirm the effectiveness of the CFS mask in suppressing conscious perception of the target stimulus.

3. Operant-Masked Block: The set up is similar to the baseline-masked block, but with an added target stimulus. After participants press the space bar, a blue circle (target stimulus) appears in a predetermined corner of the masked area 150 ms after the press, remaining on-screen for 200 ms. Participants then complete the same clock-adjustment task to report their perceived time of the button press. As with the baseline-masked block, participants report after each trial whether they saw a blue circle. A few "decoy" trials with a full-contrast circle are randomly added to monitor participants' awareness levels.

4. Baseline-Unmasked Block: This condition is identical to the baseline-masked block, except no CFS masking is used. Participants are not expected to see any target stimulus. Participants will be required to press the button at a self-chosen time, the clock stops, and they adjust the clock hand to the perceived time of their button press, as in previous blocks.

5. Operant-Unmasked Block: This condition mirrors the operant-masked block but without CFS masking, there fore the blue circle (target stimulus) is clearly visible to participants.

2x2 Design Table

Table 1 shows the 2x2 experimental design.

Experimental Design and Corresponding Hypotheses

Table 2 exibits the hypotheses and its corresponding comparasion conditions.

Results and Data Analysis

Note: So far we have only collected data from 65 participants. Therefore, only these participants' data will be analysed in this report.

Data Analysis for Hypothesis 1 (Positive Control)

Step-by-Step Analysis

The analysis workflow involves the following steps:

Step 1: Automated Data Loading (for unmasked condition)

Step 2: Calculation of Huber Mean and Paired Differences (Δ_{masked})

Step 3: Paired t-test and Effect Size Calculation (Cohen's d)

Step 4: Bootstrapped Confidence Intervals and Visualization

Step 1: Automated Data Loading for unmaksed participants

This step involves automatically loading all participant data stored in subfolders under the Awareness_and_Agency_Project_data directory.

Step 2: Calculation of Huber Mean and Paired Differences $\Delta_{unmasked}$

Table 3 demonstrates that the differences are unfortunately insignificant, meaning that the occurance of the consequence (i.e., blue circle) does not shorten participants' perceived time difference. However, since we only have 65 participants so far, and 0.0761 is apporaching significance, it is possible that once we reached the desited number the result might be significant. Further discussion will be elaborated later.

Data Analysis for Hypothesis 2

Step-by-Step Analysis

The analysis workflow involves the following steps:

Step 1: Automated Data Loading (for masked condition)

Step 2: Screening Procedure using Fisher's Exact Test

Step 3: Data Preprocessing and Filtering

Step 4: Calculation of Huber Mean and Paired Differences (Δ_{masked})

Step 5: Paired t-test and Effect Size Calculation (Cohen's d)

Step 6: Bootstrapped Confidence Intervals and Visualization

Step 1: Automated Data Loading (for masked condition)

The primary objective of this data analysis is to investigate whether operant stimuli (in this case, the appearance of a blue circle) influence temporal estimation biases under masked and unmasked conditions.

Specifically, I aim to determine if these biases are modulated by unconscious processing, ensuring that conscious awareness of the stimulus does not confound the results.

To achieve this, I implement a rigorous screening procedure to exclude trials where participants reported awareness of the operant stimulus.

The data analysis is structured as follows:

Screening Procedure using Fisher's Exact Test:

To ensure that estimation biases are due to unconscious processing, we conduct Fisher's Exact Test to compare awareness rates between operant-masked and baseline-masked conditions for each participant. If a participant reports significantly more awareness in the operant-masked condition than in the baseline-masked condition, their masked trials are excluded from further analysis.

Data Preprocessing and Filtering:

Exclude practice and catch trials that could introduce learning effects or noise. Remove trials where participants reported awareness of the operant stimulus, ensuring that only unconscious processing is measured. Calculation of Huber Mean and Paired Differences (Δ_{masked}):

Huber Mean is calculated for each participant's temporal estimation bias within both baseline-masked and operant-masked conditions. This robust measure minimizes the influence of outliers, providing a more accurate central tendency estimate than the arithmetic mean. Paired differences (Δ_{masked}) are computed to assess the influence of operant stimuli on estimation biases.

Paired t-test and Effect Size Calculation (Cohen's d):

We perform paired t-tests on the paired differences (Δ_{masked}) to test if they significantly differ from zero. Cohen's d is calculated to determine the effect size, providing insight into the practical significance of the operant stimulus's influence on temporal estimation.

Bootstrapped Confidence Intervals and Visualization:

Bootstrapping (5,000 samples) is conducted to calculate 95% confidence intervals for paired differences and Cohen's d. The DABEST package is used for estimation statistics and visualization, enabling a more comprehensive interpretation of the data.

By systematically controlling for conscious awareness and utilizing robust statistical methods, this analysis aims to provide compelling evidence on whether operant stimuli can implicitly modulate temporal estimation biases. This approach enhances the validity and reliability of the findings, contributing to our understanding of the relationship between unconscious processing and temporal perception.

Step 2: Screening Procedure using Fisher's Exact Test

Data Screening: Exclusion Criteria. In this study, a screening criterion was implemented to ensure that participants' estimations of event timing were not influenced by conscious awareness of the operant stimulus, which in this experiment was the brief appearance of a blue circle.

Specifically, participants were excluded from further analysis if they reported perceiving the blue circle significantly more often in the Operant-Masked condition than in the Baseline-Masked condition.

This criterion was established because the Baseline-Masked condition presented no operant stimuli, whereas the Operant-Masked condition presented the blue circle in a manner intended to remain subliminal.

If a participant's awareness of the blue circle was significantly higher in the Operant-Masked condition, it would indicate that the masking was ineffective for that participant, and thus their temporal estimations could be influenced by conscious perception.

To evaluate this, **Fisher's exact test** was used to compare the frequency of reported perceptions between the two conditions.

If the difference was statistically significant ($p < 0.05$), it was concluded that the participant was consciously aware of the blue circle in the Operant-Masked condition, leading to the exclusion of all their trials in the masked conditions from further analysis.

This approach ensures that the estimation biases analyzed are reflective of unconscious processing rather than being confounded by conscious awareness of the operant stimulus.

Let's first try Fisher's Exact Test with one participant's data: subject 01.

For subject 01, there are: 26 aware in operant-masked condition; 24 unaware in operant-masked condition; 5 awarenesses in baseline-masked condition; 45 awarenesses in baseline-masked condition.

Let's then produce a contingency table:

Let's conduct Fisher's Exact Test

Table 5 shows that participant 01 has significantly more "aware" in operant-masked condition than in baseline-masked condition, hence this participant should be excluded.

After applying Fisher's Exact Test to all participants, there are 53 participants left.

Step 3 Data Preprocessing and Filtering

Define a function to only inclue real trials and exclude catch and practice trials.

Also exclude trials where participants report that they are aware of the blue circle.

Step 4: Calculation of Huber Mean and Paired Differences (Δ_{masked})

We calculate the **Huber Mean** for estimation bias within each condition, which is a robust measure of central tendency that minimizes the impact of outliers. We then calculate the pairted difference for later t-test and effect size calculations.

Step 5: Paired t-test and Effect Size Calculation (Cohen's d)

Objective: Calculate Paired Differences (Δ_{masked}):

Δ_{masked} = Operant-Masked Huber Mean - Baseline-Masked Huber Mean

Measures the effect of intentional action on time estimation bias in the Masked condition.

Statistical Tests:

One-tailed Paired t-test: Test the hypothesis: $\Delta_{masked} > 0$ (indicating intentional binding).

Effect Size Calculation:

Cohen's d to measure the magnitude of the effect.

Table 6 shows that the results are far from significant, as $p = 0.322$. This means that for the sample we have so far, people do not experience intentional binding under unconsciousness condition. However, again, we are quite far from the desired 80 participants, so the results are not expected to be significant.

Step 6: Data Visualization

Figure 1 and Figure 2 shows that the distribution of Δ_{masked} is positively skewed with a peak around 0, meaning that a great number of participants' perceived time differences between maked-baseline and masked-operant is basically none.

Discussion

Since the we have not collected the desired number of participants, we cannot determine whether the results are significant or not with confidence.

Based on the results so far, however, esentially there will be three possibilities when the desired number of participants is reached:

1. Both Hypothesis 1 (Positive Control) and Hypothesis 2 (Unconscious Agency) yield insignificant

Interpretation:

First, the failure to observe a significant intentional binding (IB) effect in the unmasked operant condition (Hypothesis 1) raises concerns about the experimental design's validity in eliciting SoA. One possibility is that the task demands or stimulus presentation did not create a strong enough sense of agency in participants. For example, if the delay between action and outcome (150 ms) was not optimally calibrated, participants may not have experienced a clear action-outcome relationship, leading to weak or absent IB effects. Additionally, the method of reporting perceived action timing—such as using a rotating clock—may have introduced measurement noise or high variability, obscuring potential IB effects.

Second, the lack of a significant binding effect in the masked condition (Hypothesis 2) suggests that if SoA does exist unconsciously, it may not be robust enough to be captured through IB under these conditions. One possibility is that even if unconscious agency exists, the specific intentional binding paradigm may not be the best measure to detect it, particularly under suppressed awareness. Given that IB is traditionally studied in explicit, conscious agency tasks, it is unclear whether the same mechanisms operate effectively when awareness is removed. Alternatively, the contrast threshold calibration in the CFS masking phase may not have been precise enough, leading to either residual awareness in some participants or excessive suppression in others, making it difficult to interpret the results.

Furthermore, it is possible that SoA is genuinely not present in unconscious conditions, aligning with the Illusionist Theory, which posits that SoA is a post-hoc construction of consciousness. This would mean that the independence theory lacks empirical support—at least in this experimental setup. However, given that Hypothesis 1 was also insignificant, it is difficult to conclusively argue for or against either theoretical perspective without first ensuring that the experimental paradigm successfully elicited IB in conscious conditions.

To address these issues, future research may need to refine stimulus timing, reporting methods, and masking effectiveness to ensure that IB can be robustly measured before testing its existence under unconscious conditions.

2. Hypothesis 1 (Positive Control) is significant and Hypothesis 2 (Unconscious Agency) is insignificant

Interpretation:

One possibility is that IB fundamentally relies on conscious awareness, aligning with the Illusionist Theory. This perspective posits that SoA is a post-hoc construction, rather than an intrinsic causal mechanism. Under conscious conditions, participants perceive an outcome and retrospectively attribute agency, resulting in a subjective compression of time. In contrast, when the outcome is masked, the brain fails to establish the same causal link, and IB does not emerge. This suggests that SoA might be contingent on explicit awareness of an action's effects, rather than an automatic process that operates independently of consciousness. If this is the case, it challenges the premise that SoA is a fundamental and unconscious aspect of human cognition.

However, an alternative explanation is that Continuous Flash Suppression (CFS) may not completely block unconscious processing. While CFS is highly effective in preventing conscious perception, research has shown that some suppressed visual stimuli can still be processed at lower neural levels (e.g., V1, V4). If IB requires higher-order processing in regions such as the prefrontal cortex, but the masked condition only allowed for subthreshold sensory processing, then the expected IB effect may not have been generated. This raises a critical distinction between awareness of an outcome and sufficient processing of an outcome for IB to occur—it remains unclear whether SoA necessarily requires conscious awareness or simply a certain threshold of neural integration that CFS may have disrupted.

Another crucial factor to consider is the role of attention and task expectations in IB. Most IB studies are conducted under conditions where participants actively anticipate an outcome, strengthening their sense of agency. In our unmasked conditions, participants saw an outcome appear following their action, reinforcing their implicit causal inference. However, in the masked condition, they never consciously perceived the outcome, meaning they might never have formed the expectation of an action-outcome link in the first place. If IB relies on participants predicting an outcome before it occurs, then a lack of conscious awareness might disrupt this predictive mechanism, thereby eliminating the IB effect.

A related concern is that participants may have adopted different cognitive strategies across conditions. In the unmasked condition, participants knew that pressing the button would typically lead to an outcome, which may have strengthened their perceived causal agency. In contrast, in the masked condition, since participants never consciously saw an outcome, they may have engaged in a different decision-making process, one that did not support IB. This highlights the importance of considering how experimental conditions shape participant expectations and cognitive processing, rather than assuming that all conditions are processed equivalently at an unconscious level.

Beyond cognitive factors, the insignificance of IB in the masked condition might also be explained by methodological limitations. If IB effects are inherently weaker under unconscious conditions, the experiment may have lacked sufficient statistical power to detect them. Measurement noise, such as individual differences in sensitivity to CFS or variability in participants' subjective time perception, could have introduced additional variability, weakening the overall effect. Furthermore, if some participants retained partial awareness of the masked outcome while others did not, this could have led to high within-group variance, further obscuring any potential IB effect. Future studies could address this by incorporating post-experiment awareness checks to ensure that participants truly had no conscious perception of the outcome.

To refine our understanding of SoA in unconscious conditions, several improvements could be made. Increasing sample size may help detect more subtle IB effects, if they exist. Additionally, employing alternative unconscious manipulations—such as visual adaptation, subliminal priming, or backward masking—could determine whether the absence of IB is specific to CFS or a more general feature of unconscious processing. Finally, exploring alternative SoA measurements beyond IB might reveal whether other aspects of agency attribution persist under unconscious conditions. If IB is not the only marker of SoA, then its absence in the masked condition may not necessarily disprove the independence theory, but rather suggest that IB itself is highly dependent on explicit awareness.

2. Both Hypothesis 1 (Positive Control) and Hypothesis 2 (Unconscious Agency) becomesignificant

Interpretation:

Because H2's result is far from significant, I personally do not think that this will happen. However, if it does, then this means sense of agency does not rely on consciousness.

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Table 1

Experimental Design: 2 x 2

Condition	Blue.Circle.Appear	CFS.Masking
2. Baseline-Masked	No	Yes
3. Operant-Masked	Yes	Yes
4. Baseline-Unmasked	No	No
5. Operant-Unmasked	Yes	No

Table 2

Testing Hypotheses

Hypotheses	Conditions.Compared	Question
H1: Positive Control	4 vs. 5	Does binding occur when the outcome is visible?
H2: Unconscious SoA	2 vs. 3	Can binding occur without conscious awareness?

Table 3

Paired t-test and Cohen’s d Results for Hypothesis 1

Statistic	Value
t-value	1.4487720
df	64.0000000
p-value	0.0761417
95% CI lower	-0.0006023
95% CI upper	Inf
Mean of <U+0394>_unmasked	0.0039622
Cohen’s d	0.1796981

Table 4

Contingency Table for Subject 01

	Aware	Unaware
Operant-Masked	26	24
Baseline-Masked	5	45

Table 5

Fisher's Exact Test for Subject 01

Statistic	Value
Odds Ratio	9.511
95% CI Lower	3.571
95% CI Upper	Inf
p-value	< .001

Table 6

H2 Paired t-test and Cohen's d Results

Statistic	Value
t-value	0.4651899
df	52.0000000
p-value	0.3218689
95% CI lower	-0.0169280
95% CI upper	Inf
Mean of <U+0394>_masked	0.0065108
Cohen's d	0.0638988

Figure 1

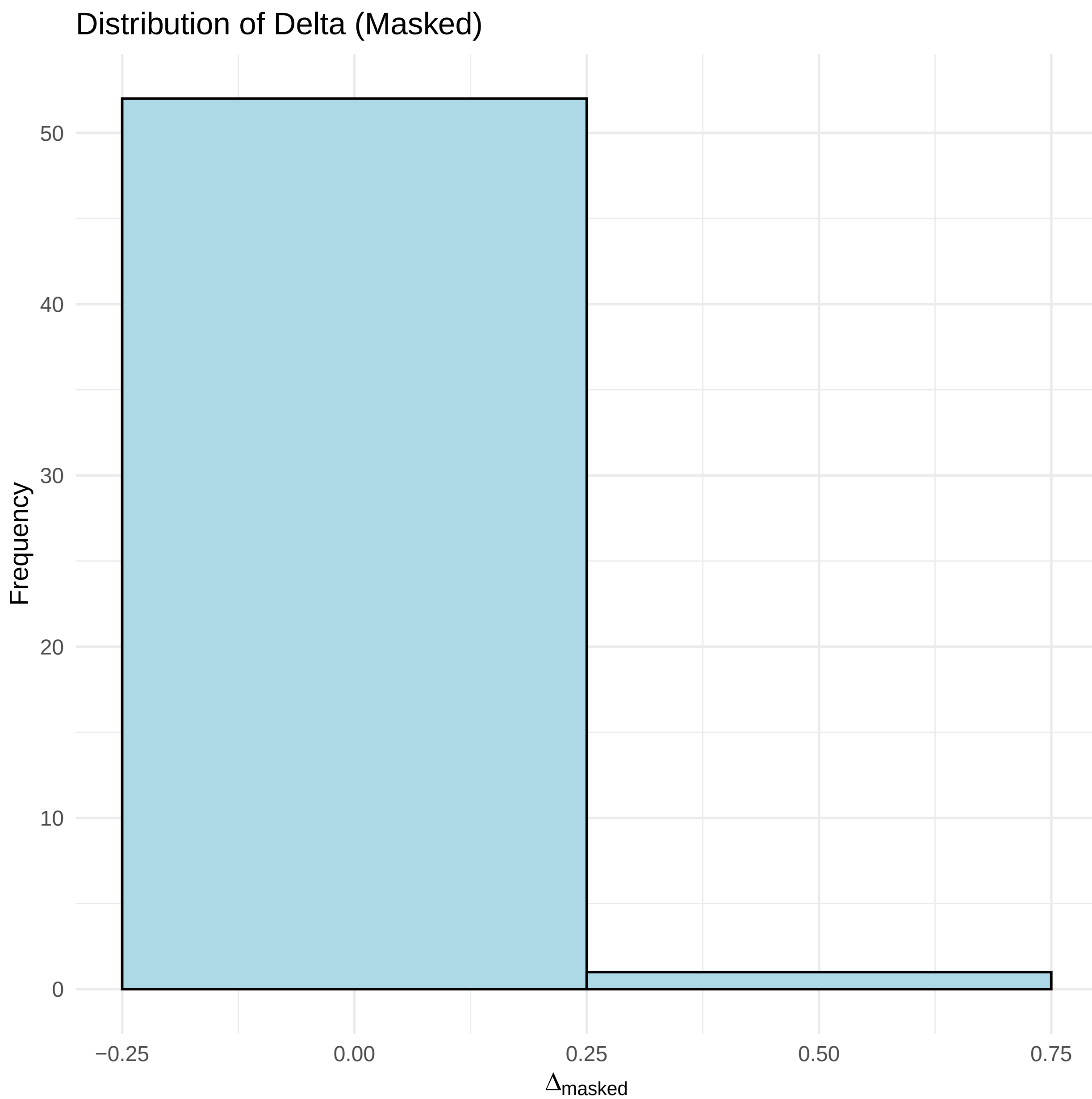
Distribution of Delta (Masked)
Frequency
50
40
30
20
10
0
−0.25
0.00
0.25
0.50
0.75
Δ_{masked}

Figure 2