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Experimental Master’s Thesis:

Subliminal Disambiguation does not Influence One-Shot Perceptual Learning

Supervisor:

Carlos González García

Co-Supervisor:

María Ruz

Student:

Ricardo De Haro Mancha

Centro Investigación Mente, Cerebro y Comportamiento (CIMCYC)

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ABSTRACT

Perception is an active process emerging from the interaction between incoming bottom-up sensory inputs and projected top-down internal priors. Priors are generally formed after repeated exposure to a stimulus. An exception is Mooney images disambiguation, a case of One-Shot Perceptual Learning. Mooney images are black and white images, without apparent meaning. However, single exposure to the real image, process known as disambiguation, is sufficient to associate the original figure and the Mooney. Disambiguation is typically achieved by clear presentation of the image. Existent literature suggest that aware or clear presentation of the unambiguous figure may not mandatory for Mooney disambiguation to occur. However, classically, disambiguation is only assessed asking participants for explicit subjective recognition. The objective of this study was to assess whether also the implicit recognition of Mooneys could be improved by the subliminal presentation of unambiguous images. Concretely, Mooneys were subliminally disambiguated and subjective recognition rates were obtained. Additionally, implicit recognition was measured in a task where participants indicated whether a red dot was located on or off Money images. No evidence was found supporting facilitation by subliminal priming in the implicit task. Nevertheless, subliminal disambiguation did influence subjective recognition. These results constitute one of the first experiments exploring potential alternatives to induce Mooney disambiguation.

INTRODUCTION

How humans process and perceive sensory information has been the subject of intense debate in psychology and, later on, cognitive neuroscience. Traditionally, perception has been conceived as a passive process where arriving stimuli trigger perceptual processing in the brain. Alternatives to this conception date back to the time of Von Helmholtz, who argued that perception is based on unconscious inference (Helmholtz & Southall, 1962). According to Helmholtz, perception is closer to recognition of prior experiences than to a passive response. In the second half of the 20th century, Marr and Gibson set the basis to our current understanding of the brain as an active agent constructing perception (Gibson, 2014; Marr, 2010). The notion of perception as a passive process was formally challenged a couple of decades ago also by the predictive coding theory (Rao & Ballard, 1999). According to this view, the brain generates internal models of the world based on statistical regularities of the environment and uses these models to predict what to expect. Bar's work was a significant contribution to our understanding of how experience-based internal models are transmitted in a top-down manner and combined with incoming bottom-up information from lower-order perceptual structures (Bar, 2021). Within this view, stimuli do not merely elicit a reaction, rather, the construction of their representation is shaped by the combination of external factors and internal models. Given the relevance of statistical regularities in the acquisition of internal models, it has been proposed that they can be conceptualized within the Bayesian inference computational framework (Parr et al., 2018). Consecutively, in the context of perception, the brain can infer the most likely sensory input based on probability distributions derived from those models. The goal of this study was to further our knowledge of how internal models are built in a special case of prediction, one-shot learning.

In the context of ambiguous stimuli, such as the hollow face illusion, the moment when the observer is shown the most likely or real interpretation of the stimulus is known as perceptual disambiguation or disambiguation for short. Following disambiguation, if the incoming stimulus aligns with the prior prediction, no further processing is required. On the contrary, if an unexpected stimulus is presented, a mismatch occurs between the sensory information and the predicted model. This mismatch indicates the brain the need to update its previous statistical model of the world. Perceptual disambiguation has been classically investigated in experimental tasks such as the oddball paradigm (Fong et al., 2020; Rapaport et al., 2023). In this paradigm, the sensory prior is established by serial, repeated presentation of the same stimulus or pattern of stimuli, creating a predictable, expected condition. On the other hand, infrequent presentation of deviant stimulus, different from the standard, causes surprise because the most likely prediction was incorrect. The brain's response to deviants is proportional to the magnitude of the change from the original stimulus and, in turn, to the magnitude of the prediction error (Southwell & Chait, 2018).

This type of statistical learning paradigms thus relies on repetition and learning of regularities. Nevertheless, perceptual learning of internal models can also occur in one-shot, as it happens in the "Mooney effect". Mooney images are black and white thresholded images that represent meaningful real-world figures (see **Figure 1**, Mooney, 1957). These stimuli are intentionally highly ambiguous, allowing for each person to elaborate interpretations of the figure's meaning or, ideally, not generate any interpretation or internal model at all. The black and white images are disambiguated by means of the corresponding greyscale image, an unambiguous version of the Mooney. Once the Mooney image is disambiguated, it is clearly and effortlessly identified: the meaning of the figure becomes clear and evident. This phenomenon is a case of one-shot perceptual learning since a single exposure to the real picture is sufficient to learn its significance, and this effect can last for long periods of time (Ludmer et al., 2011): even long after disambiguation, the main figure can be still identified, indicating that disambiguation it is not a form of temporal perceptual priming or working memory trace. It has been theorised that one-shot perceptual learning and its long-lasting effects were stablished through evolution, as a mechanism for detecting predators in the natural environment (Ishikawa & Mogi, 2011; Ramachandran, 1988). However, this explanation is somewhat teleological, and the precise mechanisms sustaining one-shot perceptual learning remain elusive.

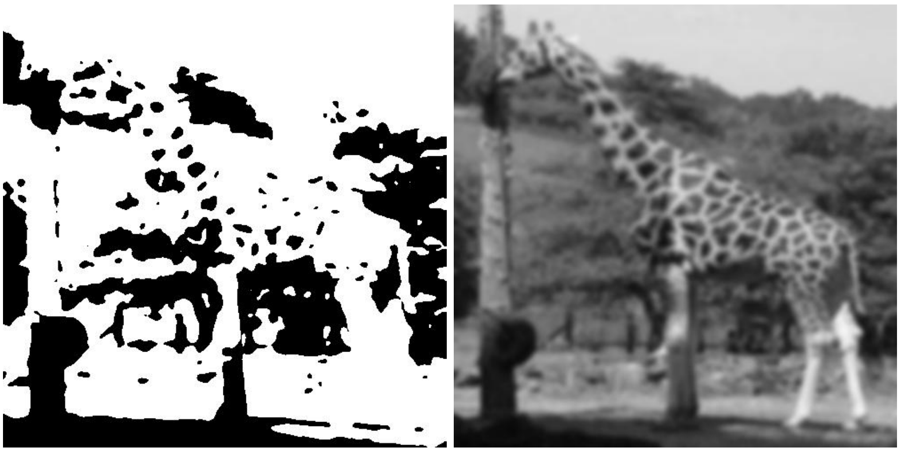

Figure 1: Mooney image (left) and its disambiguated greyscale version (right).

Disambiguation effects are systematically evaluated through explicit measures. Studies employing the Mooney paradigm commonly verify recognition by asking participants to respond in a YES/NO manner whether they recognised the image (Chang et al., 2016). Alternatively, participants can be directly asked to verbally report what they see in few words (Chang et al., 2016; Kozunov et al., 2020). However, is it possible to objectively access the internal models in the Mooney paradigm? Davies et al. (2018) presented an innovative approach designed to objectively evaluate perceptual learning in the Mooney task. Specifically, they developed a paradigm to measure implicit recognition of Mooneys, where participants were asked to respond whether a red dot was located on or off the object contained in the figure. If the participants' priors were valid and aligned with the original unambiguous image, participants would be able to accurately locate the dot. The authors were indeed able to estimate indexes derived from Drift Diffusion Models and Signal Detection Theory, enabling them to quantify implicit perceptual learning without directly asking the participant.

Based on the paradigm from Davies et al. (2018), Beilner (2022) extended the dot task. During an initial Dot-phase, they replicated the task from Davies et al. (2018), including additional measures of Response Times (RT). In a second phase, participants indicated whether they recognised the figure or not, providing a categorical YES/NO answer. Subjective explicit recognition measures were obtained during this phase and could be compared to the implicit recognition performance from the first phase. Employing this paradigm, Beilner (2022) demonstrated that previously disambiguated images were recognized better than control, or catch, images that were never disambiguated but were equated in the number of presentations. Additionally, participants improved at extracting relevant information from non-relevant noise in the image following disambiguation, as indicated by measures derived from the Signal Detection Theory (Stanislaw & Todorov, 1999). Importantly, these results revealed that the dot task tracked perceptual learning to a similar extent that subjective measures.

The objective of the current study is to further characterise the disambiguation of Mooney images using the objective, implicit paradigm validated by Beilner (2022). More specifically, we focus on whether the perceptual prior afforded by the unambiguous image can be established when this crucial information is presented subliminally. To our knowledge, only one study has focussed on subliminal disambiguation of one-shot perceptual learning. Research by Chang et al. (2016) provided evidence that unconsciously perceived stimuli were able to influence performance in a Mooney recognition task. In this study, the authors briefly presented the unambiguous version of Mooney images for a short interval of time (17ms), followed by a mask. Specifically, their mask was created adding phase shuffled noise to blur the target grayscale. Importantly, each mask was specifically derived from the presented picture. At the end of the trial, the participants were shown the Mooney version and were asked whether they recognised the figure. Their findings indicated that although subjects were unable to consciously recognise the Mooney version in the initial presentation, they became better at identifying the figure when the images had been subliminally presented. Noteworthy, this effect was observed exclusively for the regular images and not for the control catch images. These results suggest that even without reaching conscious awareness, unconsciously processed grayscale pictures can contribute to the establishment of a prior that guides behaviour during posterior encounters with the Mooney version of the stimulus. However, it is important to note that replication of subliminal effects can be challenging, and this highlights the need for further replications. Importantly, this subliminal study employed explicit measures of learning, asking participants for subjective recognition. Thus, here we aimed at obtaining further evidence of subliminal effects on perceptual learning when using objective, implicit recognition indices.

Our study aimed to address whether subliminal disambiguation would impact the implicit recognition of Mooney images. To answer these questions, we extended the task of Beilner (2022), which assessed implicit and explicit Mooney images recognition simultaneously, to include a subliminal disambiguation manipulation, as used by Chang et al. (2016). Based on previous evidence using subjective measures, we hypothesized that, if perceptual priors can be established subliminally, then we should observe implicit recognition of the corresponding Mooneys in our task. Consequently, we expected to observe reduced error rates during the Dot task for regular Mooney images after subliminal disambiguation while no changes were predicted for the catch images (which corresponding gray scale image was never presented). Similarly, we also expect reduced Responses Times and improved Discrimination rates (indexed by d'). Moreover, we evaluated whether subliminal disambiguation also led to increased subjective recognition. In this regard, we hypothesized that for a real subliminal effect to be considered, improvement in objective, implicit measures of learning should occur even in the absence of a change in our subjective experience. Thus, we expected no significant differences in explicit Subjective Recognition following subliminal disambiguation.

METHODS

All hypotheses and analyses were preregistered in the platform 'ASPREDICTED' and can be accessed following this link: https://aspredicted.org/k2r7c.pdf.

Participants

Forty-four participants (9 males, 34 female, 1 non-binary, M = 21.4 years, SD = 3.73) took part in the experiment. No participants were excluded. The power analysis for the paired t-test (post vs. pre-disambiguation in Masked images) – (post vs. pre-disambiguation in catch images) estimated that 41 participants would be needed to detect a medium effect size (Cohen's d = 0.4) with 80% power. Participants were recruited via SONA (https://ugr-cimcyc.sona-systems.com/), the local platform for participants recruitment. The study followed the Declaration of Helsinki ethical guidelines and had approval from the Ethics Committee for Research with Human Participants of the University of Granada, prior to data collection (ref. 1816/CEIH/2020).

Apparatus and stimuli

The task was coded in Psychopy, version v2022.2.4. The stimuli were presented on a Asus TUF Gaming VG2791R monitor connected to an Intel Core i7-11700 2.50GHz computer. Data analyses were carried out in R-4.2.3 for Windows.

Images were the same as used by Beilner (2022), consisting of a set of pictures extracted from the Caltech 256 dataset (Griffin et al., 2022). They were resized into a 500x500 pixel shape, and then converted to greyscale images. These were the grey unambiguous images used for subliminal disambiguation to provide meaning to the Mooneys. Mooney images were obtained after smoothing and thresholding of the greyscale versions. They were voided of meaning, which forced participants to guess the contained figure from the original picture. We selected the same 24 images that were previously used by Beilner (2022), as their effectivity was proven in the original study and a pilot study. From each of the 24 selected images, 8 different were obtained: 1 greyscale, 1 Money and 6 Mooneys with a red dot. 3 of the images contained the dot inside (ON) the main figure, while the other three had the dot outside (OFF) the main figure. In total, 144 different visual stimuli were used per participant. The dots were manually placed at approximately equal distance from the midpoint of the image (Davies et al., 2018)

Additionally, the mask employed throughout the task consisted of a merged version of three grey images. Subsequently, a gaussian filter was applied to this merged image. The resultant final mask alternated patches of dark and light, resembling random noise (see **Figure 2**).

Experimental Design and Procedure

The study followed a within subject design. There were two independent variables: 'Image Type' (Catch vs Masked) and exposure 'Condition' (Pre-Disambiguation vs Post-Disambiguation). Recognition Rate of Subjective Recognition was the dependent variable acquired during Recognition-phase. The two dependent variables of interest during the Dot-phase were Error Rate and RT. We then derived d' from the error rates.

The types of Mooney images could be ‘Masked’ or ‘Catch’. Masked images were disambiguated at some point of the experiment by subliminally presenting its grey counterpart. On the other hand, Catch images were never disambiguated and no additional cue was provided for their interpretation. They served as control for learning and familiarity of repeated stimuli, providing a baseline to compare the Condition effect (Pre- and Post-Disambiguation).

The experiment consisted of two phases: Dot-phase and Recognition-phase (see **Figure 2**). Each Dot-Phase was followed by a Recognition-phase. During the Dot-phase, Mooney versions were displayed to the participants. A red dot was presented either ON or OFF the figure. Participants were instructed to indicate whether the dot was located inside or outside the main figure contained in the black and white pattern. Participants responded by pressing a key (d/k, counterbalanced across participants). Dot location was different across trials of the same original picture. During the Recognition-phase, a Mooney image was presented with no dot on it. In the case of the Masked images, the grey-scale counterpart was quickly displayed to participants for the duration of a single refresh rate (17ms) at the beginning of the trial. This was the subliminal presentation. The image was followed by a blank of 50ms and then by 1933ms presentation of the mask. We followed the exact timing and presentation times of the experiment using subliminal disambiguation by Chang et al. (2016). Finally, the Mooney version was displayed. In the case of Catch images, the subliminal presented image was the same Mooney, thus participants were never presented with its grey unambiguous picture. Participants were asked to indicate by means of another pair of keys, different from the Dot-phase buttons (l/s, counterbalanced across participants), whether they recognised the object in the image or not. In both, Dot and Recognition-phases, images were displayed until the participant pressed a key. RT were collected only for the Dot-phase.

The experiment consisted of nine blocks, each of them containing a Dot-phase and a Recognition-phase (see **Figure 2**). During each Dot-phase, six different Mooneys were presented, each with six different dot configurations, adding up to a total of 36 images per Dot-phase. Three out of those six images were already subliminally disambiguated during Recognition-phase (Condition Post-Disambiguation) while the other three were new (Condition Pre-Disambiguation). Consecutively, there were 6 recognition trials per Recognition-phase and block: 3 were Catch images while the remaining 3 were Masked images. Similarly, in Recognition-phase, also half of those 6 images were Pre-Disambiguation while the other half were Post-Disambiguation. The only exception was the initial block, containing only three Pre-Disambiguation Recognition images, and the last block, containing only three Post-Disambiguation Recognition images.

The sequence of events in a Dot-phase trial were the following: Mooney image with one of the six red dot configuration was displayed. There was no fixation point. Stimulus was displayed until participant responded by key pressing. The sequence of events in a Recognition-phase trial were the following: Greyscale image was presented for 17ms. It was followed by a short blank of 50ms before the mask was presented for 1933ms. Finally, the Mooney version was displayed until participant indicated Subjective Recognition by pressing a key.

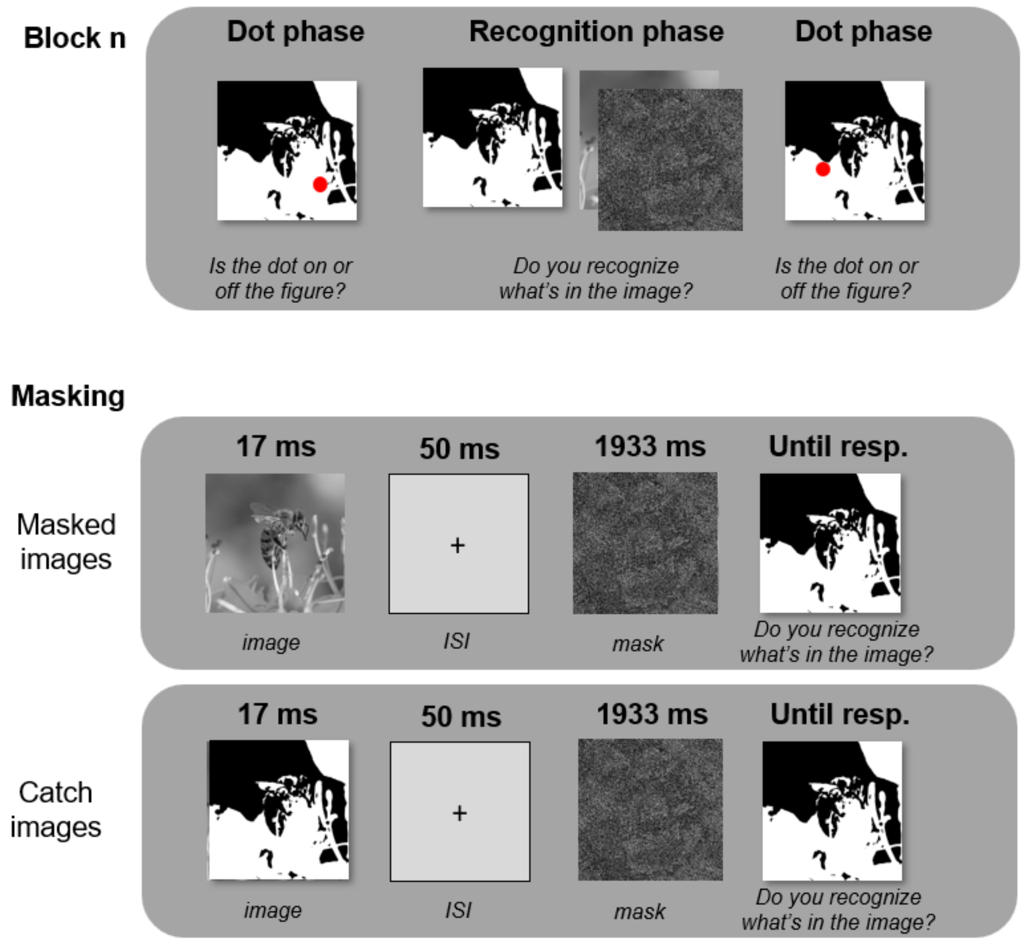

Figure 2: Experimental phases and stimulus types. The experiment contained a Dot-phase measuring implicit recognition and a Recognition-phase measuring explicit recognition. The masking figure represents the sequence in a single Recognition-phase trial for Catch or Masked images. In the case of Masked images, the greyscale unambiguous picture was subliminally presented, followed by a mask. The Mooney version was displayed and participants were asked about Subjective Recognition. In the case of Catch images, the same Mooney was presented twice, before and after the mask.

Participants were received at the lab and asked to fill in an informed consent form. Participants read the instruction on their own, received an additional short explanation and had some time to ask further questions. To minimize the learning effect on disambiguation, and given the simplicity of the task, no practice trials were included.

Participants first completed the first Dot-phase. They were asked to follow the instructions: ‘Press d [k] if the dot is ON the figure. Press k [d] if the dot is OFF the figure.’. RT were collected as the interval between Mooney image display and key press response. Responses ON/OFF were also collected to obtain error rates. Error Rate was calculated as the percentage of wrong classifications (M+FA/total). During Recognition-phases, participants were asked to follow the instructions: ‘Press s [l] if you RECOGNIZE the figure. Press l [s] if you DO NOT RECOGNIZE the figure’. As interpreting Mooneys is a reflected process, participants were not rushed to respond quick. The same structure was repeated across the nine blocks that constituted the experiment, for a total of 348 trials. The experiment lasted for 25-30 minutes. After the experiment, participants were asked, in a non-standardized manner, about their experience to gain further insights about the subliminal manipulation. They were also given an overall explanation of the experiment's goals and hypotheses.

Statistical Analysis

Preregistered Analyses

The Recognition Rates during Recognition-phase of Money images Pre- and Post-Disambiguation were compared in a two ways ANOVA with Image Type and Condition as main factors.

Signal detection theory was used as well to evaluate performance during the Dot-phase. In our experiment, the two possible choices are ON, inside the main figure, or OFF, outside the main figure. The trial was considered a Hit when participants correctly located the dot ON the figure (true positive). The trial was a Miss when the participant incorrectly reported the dot OFF when it was ON the figure (false negative). The trial counted as correct rejection when the participant correctly located the dot OFF the figure (true negative). Finally, the trial was a False Alarm (FA) whenever the participant reported the dot ON the figure when in fact the dot was located OFF the figure (false positive). The Discrimination Rate was computed following the formula: $d' = z(Hit) – z(FA)$.

Error Rates, RTs and d' during Dot-phase were compared separately in two-way ANOVAs, with Image Type (Catch, Masked) and Condition (Pre-Disambiguation, Post-Disambiguation) as main factors.

Exploratory Analyses

We explored another parameter derived from signal detection theory, the Response Criterion c, calculated as $c = -0.5*(Hit + FA)$ (Stanislaw & Todorov, 1999).This criterion reflects the response tendencies of participants. A c below 0 indicates that participants respond in a liberal way. That is, participants tend to respond that the signal is present ON the figure. On the contrary, a c greater than 0 indicates a conservative criterion, meaning that the participant is more likely to respond that the signal is not present, OFF the figure. If, following disambiguation, participants are certain that the signal is present, a shift in c is expected to occur from a more conservative to a more liberal criterion.

Additionally, we downsampled to specifically target subsets of trials where our subliminal manipulation was successful as reported by subjective report. Specifically, a first subset (Disambiguated) contained images that were not recognized before the subliminal disambiguation but were identified afterwards. A second subset (Not-Disambiguated) consisted of the images that were never recognised, neither in Pre-Disambiguation nor in Post-Disambiguation. By means of this targeted downsampling we made sure to select subsets that where the effect would be most likely present, but we also reduced drastically the number of trials (from 12382 to 4218 Dot-phase trials). All Dot-phase trials associated with each image belonging to either of the subsets were included. Disambiguated and Not-Disambiguated subsets were considered only for masked images so Catch trials were excluded.

RESULTS

Preregistered Analysis

Subjective Recognition

Image Recognition was low in all conditions (see **Figure 3**, **Table 1** and **Table 2**). The ANOVA results showed that Recognition Rates did not differ across Image Types. There was a significant effect of Condition ($F = 18.006$, $p < 0.001$), as Subjective Recognition was lower before ($M = 0.393$, $SD = 0.280$) than after disambiguation ($M = 0.452$, $SD = 0.293$), but this was equal for Masked and Catch images ($Fs < 1.971$, $ps > 0.168$).

Table 1. Subjective Recognition results. Means and Standard Deviation for all four conditions.

	image type	mean	SD
pre	catch	0.394	0.289
	regular	0.392	0.275
post	catch	0.436	0.289
	regular	0.468	0.299

SD = Standard Deviation

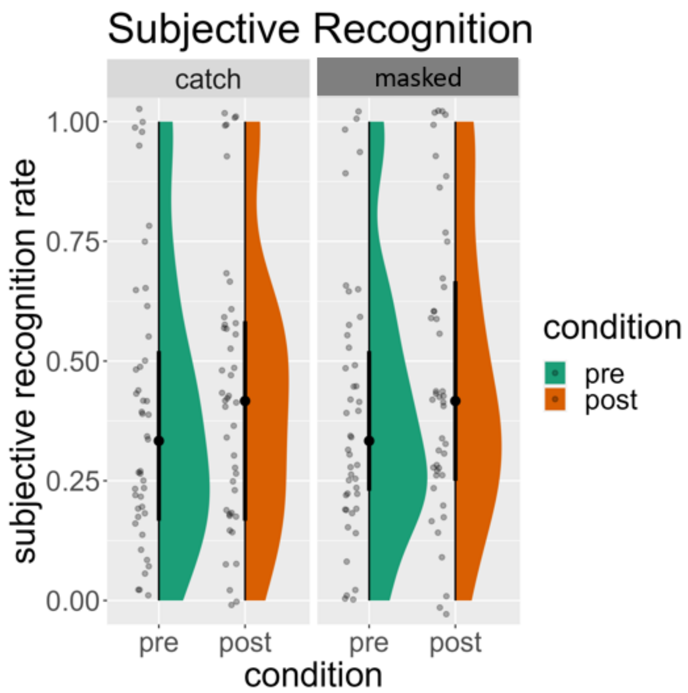

Figure 3: Subjective recognition during Recognition-phase. For both Image Types, Catch and Masked.

Error Rates, RT and d'

No participant was excluded due to low performance. Considering only Dot-phase trials, 2.29% of trials were discarded because the participant responded too slow (more than 10000ms after stimulus onset) and no trial was discarded because the participant responded too fast (faster than 200ms). Contrary to our main hypothesis, the Error Rates ANOVA (see **Figure 4A** and **Table 2**) showed no significant differences for the main effect of Image Type, Condition or the interaction between the two (see **Table 2**, all Fs < 1.389, all ps > 0.245).

Additionally, we studied differences in RT (see **Figure 4B**) and d' (see **Figure 4C**). There was a significant main effect of Condition (Pre- vs. Post-Disambiguation) on RT ($F = 159.559$, $p < 0.001$), as participants responded faster at Post- ($M = 1440$ms, $SD = 518$) than Pre-Disambiguation ($M = 2049$ms, $SD = 778$). However, there were no significant differences for the Image Type or the interaction between Condition and Image Type (Fs<1.000, ps>0.323). As for the d' (see **Figure 4C** and **Table 2**), no significant differences were found for Image Type, Condition or their interaction (all Fs < 1.287, all ps > 0.263).

Table 2: ANOVA results for all the measures calculated. Statistic associated value (F) and p-values for every main and interaction effect. Significance is indicated by a star.

		F	p-value
recognition	condition	18.006	< 0.001*
	image type	0.312	0.579
	interaction	1.971	0.168
ER	condition	0.097	0.757
	image type	1.389	0.245
	interaction	0.701	0.407
RT	condition	159.559	< 0.001*
	image type	0.147	0.703
	interaction	1.000	0.323
d'	condition	0.189	0.666
	image type	1.287	0.263
	interaction	0.527	0.472
c	condition	0.078	0.781
	image type	0.502	0.482
	interaction	0.149	0.701

ER = Error Rate, RT = Response time.

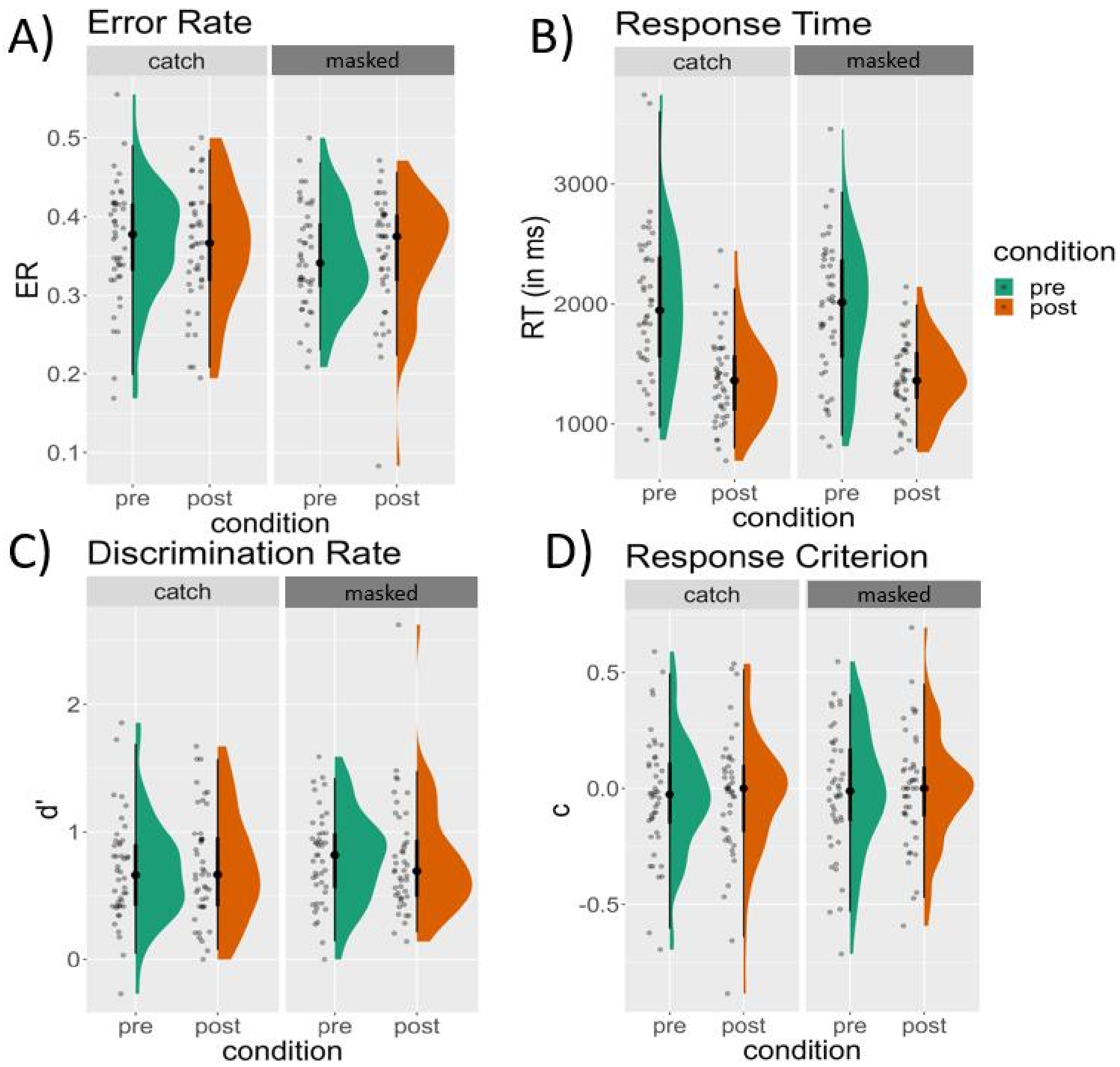

Figure 4: Main results. A) Error Rate results. **B)** RT results. **C)** Results for the Discrimination Rate (d'). **D)** Results for the Response Criterion (c). RT = Response Time.

Exploratory analyses

Criterion

No significant differences in c (see **Figure 4D** and **Table 2**) were found for the main effect of Image Type, Condition or their interaction (all Fs < 0.502, all ps > 0.482).

Subsets analysis

Contrary to our hypotheses, we did not observe a significant effect of subliminal disambiguation. To further explore our data, we used the subjective recognition data to select (1) the subset of images where disambiguation followed the classic Mooney effect pattern (no identification Pre-Disambiguation, identification Post-Disambiguation) and compared it with a (2) the subset of images that were never subjectively identified. We then performed ANOVAs on the dependent variables of the Dot task with the factors Subset (Disambiguated vs. Not Disambiguated) and Condition (Pre vs. Post). We reasoned that subjective recognition could be a potential boundary condition for the subliminal effect to impact implicit measures of learning, so that objective learning would be accompanied by a change in the subjective experience. This rationale would predict in turn no changes in objective measures of learning in the absence of increased subjective recognition.

Regarding Error Rates (see **Figure 5A** and **Table 3**), there were no significant effects of Condition, Subset or their interaction (all Fs < 2.882, all ps > 0.101). Regarding the RT ANOVA (see **Figure 5B** and **Table 3**), we observed no significant effect of Disambiguation nor interaction effect (Fs < 0.403, ps > 0.531) but a significant effect of Condition (F = 56.656, p < 0.001). RT were faster for Condition Post-Disambiguation (M = 1436ms, SD = 520) than Pre-Disambiguation (M = 2051ms, SD = 795). In d' (see **Figure 5C** and **Table 3**), we observed no significant main effect Condition, Disambiguation or the interaction effect (all Fs < 4.012, p > 0.055). Similarly, subset Response Criterion c ANOVA results (see **Figure 5D** and **Table 3**) were not significantly different for Condition, Subset nor the interaction effect (all Fs < 3.279, all ps > 0.081).

Thus, overall, and in contrast with our hypothesis, we did not find an effect of the image subset in our main DVs.

Table 3: Results for the subsets in the exploratory analyses. Statistic associated value (F) and p-values for every main and interaction effect. Significance is indicated by a star.

		F	p-value
ER	condition	0.165	0.688
	recognition	2.882	0.101
	interaction	1.476	0.235
RT	condition	56.656	< 0.001*
	recognition	0.025	0.875
	interaction	0.403	0.531
d'	condition	0.412	0.526
	recognition	4.012	0.055
	interaction	0.984	0.330
c	condition	0.046	0.831
	recognition	3.279	0.081
	interaction	2.285	0.142

ER = Error Rate, RT = Response time.

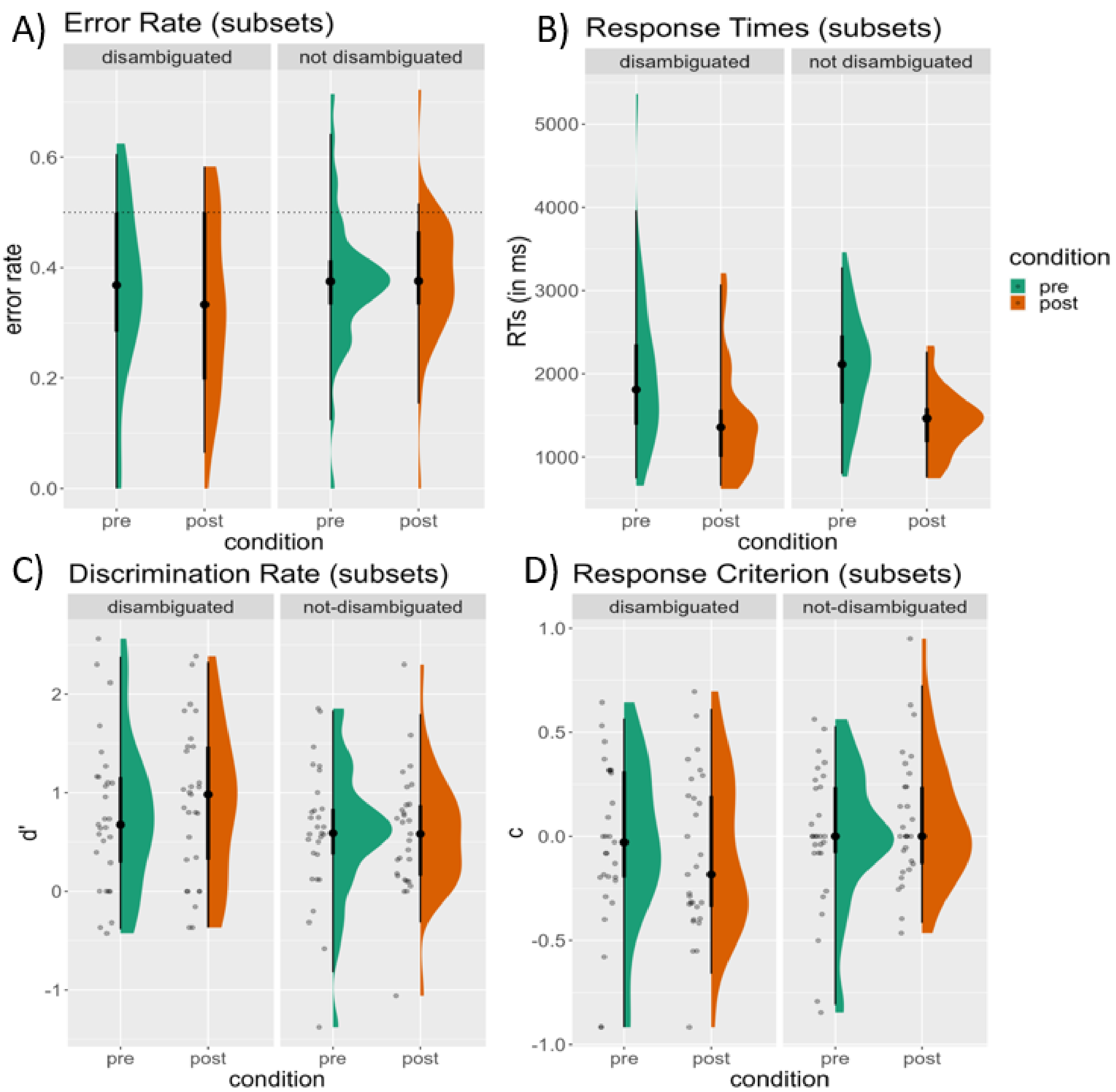

Figure 5: Main results on sample subsets. A) Error Rate results in the subset. **B)** RT results in the subset. **C)** Results for the Discrimination Rate (d') in the subset. **D)** Results for the Response Criterion (c) in the subset. RT = Response Time.

DISCUSSION

The objective of this study was to assess whether the implicit recognition of Mooney images could be improved by the subliminal presentation of unambiguous images. Based on existing literature, we predicted that implicit recognition would improve for the disambiguated images compared to images that were never disambiguated, even in the absence of changes in explicit subjective recognition. Nevertheless, our hypotheses could not be verified. No significant differences were found across the different conditions in the implicit recognition task. Neither did the exploratory analyses targeting subsets of trials. The only significant results were the main effect of Condition on the RTs and Subjective Recognition Rates. The effect on RT was, however, of no relevance to our hypotheses, as it was observed also for catch images, suggesting rather an effect of image repetition. Thus, our results suggests that subliminal disambiguation does not have the same impact on one-shot perceptual learning that was found employing explicit disambiguation. Limitations of the current study are further discussed below.

We failed to replicate the subliminal influences observed by Chang et al. (2016) in one-shot perceptual learning of Mooneys when using objective implicit measures. Specifically, Error Rates and d' did not differ following disambiguation of Masked images in the Dot-phase. Given the present results further studies are needed to discard false positives in previous literature. Alternatively, lack of statistical power could explain the lack of significant results. The sample size of this study almost doubled the sample used by Chang et al. (2016). The results are robust and did hold after subsampling targeting specific subsets. Furthermore, using the implicit paradigm with a sample as big as ours, presenting images explicitly, the size effect reported was big enough (Beilner, 2022). Therefore, it seems unlikely that increasing the sample size, a significant effect will be observed.

Beyond the absence of effect on implicit recognition rates, methodological differences could account for these results. Firstly, the time of subliminal presentation might have been too brief to enable successful processing. Although we maintained the timing employed in the research of Chang et al. (2016), subtle differences on screen characteristics of ambient luminance may have affected presentation conditions, lowering the overall energy of the information and thus its effect on neural processing. Current research recommends durations between 10-100ms for rapid priming (Elgendi et al., 2018). Exposures as brief as 33ms are not short enough to ensure unconscious processing and sometimes participants are still capable to identify the stimuli (Pessoa et al., 2005). However, interindividual differences are not taken into account. There is significant variability on how participants process stimuli according to this temporal window, but also on how they report their experience. In our sample, while some participants reported not being aware of the subliminal presentation, other participants reported to clearly perceive the greyscale picture preceding the Mooney version. Our study did not include validation of the subliminal manipulation or standardized questions. A possible step further is to customize the subjective conscious perception threshold and timing for each participant before starting the experiment (e.g. Ishikawa & Mogi, 2011)

A second important methodological difference with Chang's study is related to the spatial processing of visual stimuli. Chang et al. (2016) included a red dot in the figure as fixation point at the centre of the screen to ensure that all participants stared the same location. We, on the contrary, did not include any fixation point. During the Dot-phase of implicit recognition, participants were required to report on a red dot positioned at different locations. In our case, not including a fixation point was a forced methodological choice. Furthermore, subliminal presentation is quick, limiting thus the processing span. What kind of information is incorporated will greatly depends on the gaze spotting relevant features of the figure. For instance, a participant who spots a spiral tail on the subliminal image could infer a pig on the image. Whereas other participant, who by chance is focusing in the head, may encode only low order features such as the abstract shape of a four limbs animal. Future studies are recommended to include a fixation point. This is almost mandatory in EEG studies, to control for eye-movement artifacts. A different alternative to control for gaze position is to include eye-tracking measures (Król & Król, 2018).

A third methodological difference is the mask being used. Chang et al. (2016) used a customized mask of phase shuffled noise created particularly from each image displayed on the trial, resulting in a blurred greyscale version of the original picture. In our study, we used a universal mask of gaussian noise, i.e., the same masking for all images. Our mask (see **Figure 2**) did not contain information of the figure to be recognised. Contrary, Chang's mask could be facilitating recognition by providing information of the image extended periods of time. We consider it is better to use a universal mask since it does not provide any additional cue during the mask presentation.

A final methodological concern relates to the subliminal manipulation itself. While Chang et al. (2016) assessed effect on One-Shot Perceptual Learning explicitly, we used an implicit task to objectively study disambiguation. It is possible that the subliminal effect can be observed when we use an explicit recognition task but it does not transfer well into our implicit task or the type of learning achieved is not useful in this task. This issue is even more pressing when considering that several seconds spanned between the prime presentation (in the Recognition phase) and the Dot-phase trials. Subliminal effects are expected to result in reduced size effect compared to explicit presentation (Frumento et al., 2021). It is possible that even if a subliminal influence exists, the impact and possible benefits on time-distant processing and behaviour will be scarce compared to normal explicit presentation of the stimulus. Future studies could thus explore whether embedding the subliminal manipulation in the dot-phase leads to benefits in the objective measured proposed here. However, this issue deserves further discussion: if perceptual priors can be established subliminally, and such disambiguation does not differ qualitatively from regular learning, then these priors should be robust and long-lasting. Alternatively, if such effect is only observable under precise conditions, it would important to consider the relevance of such small or not generalizable effects and whether such disambiguation can be comparable to regular one-shot perceptual learning. Nevertheless, as literature is scarce in this area, it would be interesting to replicate the subliminal manipulation using a different paradigm.

There are important limitations in our study worth mentioning. Subjective Recognition was assessed in a rather simplistic manner, asking for a YES/NO answer. Initially, we thought that verbal report would complicate excessively data analyses. This problem can be solved coding the responses as an additional binary categorical variable ('correct answer'). In one study, researchers asked the participants for a single word report and define categories a posteriori based on the sample most common responses (Kozunov et al., 2020). Other authors considered the responses correct only if the participant response matched the words included in a list defined beforehand (Chang et al., 2016).

Summarizing, the presented results do not provide evidence in favour of subliminal unconscious processing facilitating top-down perception of Mooney images. However, our study also presented a series of methodological limitations. It is important to find adequate, individualized, presentation times for subliminal disambiguation as well as employing an uninformative universal mask. Subjective recognition should also be directly verified asking for participant's report and performing both frequentist and Bayesian statistics. Additionally, future studies can deep in our understanding of one-shot perceptual learning. Our results suggest that subliminal visual priming does not improve implicit recognition. However, whether other forms of disambiguation, such as semantic priming, could establish an influence as strongly as explicit visual disambiguation does is unclear. Another question that has not been addressed yet refers to the nature of disambiguation. Can the disambiguation process be considered a whole different independent computation or, on the contrary, is simply recycling other subsystems such as recognition and memory? Neuroimaging tools can shed some light on the underlying neural changes that takes place during disambiguation.

CONCLUSION

In this study we examined the influence of subliminal disambiguation on one-shot perceptual learning of Mooney images. Evidence investigating the origins of internal models during one-shot perceptual learning is scarce. To date, only one study has focused on creating priors using subliminal disambiguation rather than explicit disambiguation. We sought to verify subliminal influences on one shot perceptual learning using implicit, objective, measures. Our results seem to indicate that there is no such effect, and that one-shot perceptual learning needs of explicit, evident, disambiguation. These results are robust and held even after targeted subsampling. Despite methodological and theoretical differences with previous literature, it seems unlikely that subliminal priming can be of relevance. Alternatively, the subliminal effect could be potentially observed under limited conditions. These results call for further replication following the provided guidelines or, perhaps to focus on other unanswered question to deep our understanding of the disambiguation and one-shot perceptual learning.

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