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Masked blindsight in normal observers: measuring subjective and objective responses to two features of each stimulus

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Abstract

Recent visual masking studies that have measured visual awareness with graded subjective scales have often failed the show any evidence for unconscious visual processing in normal observers in a paradigm similar to that used in studies on blindsight patients. Without any reported awareness of the target, normal observers typically cannot discriminate target's features better than chance. The present study examined processing of color and orientation by measuring graded awareness and forced-choice discriminations for both features in each trial. When no awareness for either feature was reported, discrimination of each feature succeed better than expected by chance, even when the other feature was incorrectly discriminated in the same trial. However, the characteristics of the mask determined whether or not masked blindsight was observed. We conclude that when the processing channels are free from intra-channel interference, unbound or weakly bound features can guide behaviour without any reported awareness in normal observers.

Key words: awareness, blindsight, masking, unconscious, visual perception

1. Introduction

Most of participants and researchers believe that unconscious processing can guide action, shown as higher than chance-level performance in response to unseen stimuli, although they express the concern that this phenomenon of unconsciously guided action has not been convincingly demonstrated (Peters & Lau, 2015). An important body of evidence supporting unconsciously guided behavior in forced-choice discrimination tasks has been provided by patients with blindsight. They suffer from a blind area in their visual field, due to damage in the primary visual cortex. The patients are able to discriminate features of stimuli presented to their blind field (Pöppel, Held, & Frost, 1973; Weiskrantz, Barbur, & Sahraie, 1995). In spite of subjective unawareness, they can discriminate, for example, orientation, direction of motion, and simple shape of visual objects better than expected by chance in forced-choice tasks. The phenomenon of blindsight has had a considerable impact on theorizing about the neural basis of unconscious vision and the distinction between conscious and nonconscious visual processes. It suggests that unconscious visual stimuli are able to guide behavior and that the primary visual area is necessary for conscious vision but not for unconscious one. However, while some of the patients do not report any kind of awareness the stimulus (Type 1 blindsight), others have some kind of feelings of the stimulus (Type 2 blindsight) indicating that in some sense they are aware of the presence of the stimulus.

In neurologically normal participants, a visual stimulus can be rendered unseen or unconscious with visual masking (Breitmeyer & Ogmen, 2006), allowing one to study unconsciously guided action in normal population. The existence and nature of mask-induced blindsight-like phenomena in normal observers has been a controversial topic from the beginning of research (Kolb & Braun, 1995; Meeres, & Graves, 1990; Morgan, Mason, & Solomon, 1997) and it still continues to be (e.g., Peters & Lau, 2015; Song & Yao, 2016). There are several methodological and statistical approaches which are not directly comparable (Rothkirch & Hesselmann, 2017), and it is also possible that the measures of awareness or performance are underpowered, leading to false positive or false negative findings (Vadillo, Linssen, Orgaz, Parsons, & Shanks, 2020). The controversy is partly due to different ways of defining and measuring awareness. Subjective awareness of the stimulus has been often measured with a binary scale (e.g., “seen” vs. “unseen” or “aware” vs. “unaware”), which may provoke the observers to report unawareness of the stimulus even though they may have had a weak visual experience (Overgaard, 2011; Overgaard, Rote, Mouridsen, & Ramsøy, 2006).

Recently, it has become popular to measure awareness with graded scales, such as the four-point Perceptual Awareness Scale (PAS)(Ramsøy & Overgaard, 2004) in which observers report the clarity of their perceptual experience using categories such as “no experience,” “brief glimpse of something,” “almost clear experience,” and “clear experience”. Research with graded scales has shown that awareness of low-level visual features is graded rather than dichotomous (Ramsøy & Overgaard, 2004; Windey, Vermeiren, Atas, & Cleeremans, 2014). Graded subjective awareness, assessed with PAS, correlates strongly with behavioral performance in forced-choice tasks (Ramsøy & Overgaard, 2004; Sandberg, Timmermans, Overgaard, & Cleeremans, 2010; Windey, Gevers, & Cleeremans, 2013) and measures of neural activity (Christensen, Ramsøy, Lund, Madsen, & Rowe, 2006; Tagliabue, Mazzi, Bagattini , & Savazzi, 2016). Confidence ratings are metacognitive judgments in which participants express their confidence about how accurate their response was. Subjective awareness measured with graded confidence ratings also correlate strongly with behavioral accuracy (Sandberg et al., 2010; Szczepanowski, Traczyk, Wierzchon, & Cleeremans, 2013).

Majority of the studies with graded perceptual scales on masked blindsight in normal participants have failed to observe better than chance-level performance when the observers report that they were completely unaware of the stimulus (i.e., reported “no experience”) (Andersen, Overgaard, & Tong, 2019; Lähteenmäki, Hyönä, Koivisto, & Nummenmaa, 2015; Ramsøy & Overgaard, 2004; but see Song and Yao , 2016). A similar result has been reported also for some patients who can be classified as having Type 1 blindsight with typical dichotomous yes-no subjective scale (i.e., “seen” vs. “unseen”, “aware” vs. “unaware”), suggesting residual conscious vision in these cases (Mazzi, Bagattini, & Savazzi, 2016; Overgaard, Fehl, Mouridsen, Bergholt, & Cleeremans, 2008). However, when the observers report having seen “glimpse of something”, the discrimination performance is clearly above chance-level in forced-choice tasks. The studies show that performance exceeds chance-level in normal observers only when the observers are aware that something was displayed, that is, the results provide evidence, at best, for Type 2-like masked blindsight in which the observer is aware of the stimulus but not necessarily of the feature that is relevant for performing the task. The behavior in normal participants is similar to that of blindsight patients in that they report that they cannot identify what they saw, but different because they had a visual experience, whereas the Type 2 blindsight patients do not report any visual experience, only a sense or feeling that something was presented. Therefore we call the phenomenon in normal observers as “Type 2-like blindsight”. Another difference between what we call “masked blindsight” is that the participants have a normal brain, whereas the concept of “blindsight” refers to cases who have a lesion in the primary visual cortex (V1).

In typical experiments on unconscious cognition, performance and subjective awareness is measured in response to only one feature of the target. In the present study, we measured them in response to two features in each trial. We designed a procedure which allowed us to measure discrimination accuracy and subjective awareness in response to two features of the same stimulus in each trial under backward masking in normal observers. We combined objective forced-choice tasks and PAS ratings so that with a single response the observers could indicate both their forced-choice discrimination and subjective awareness of the target feature. In each trial, two responses were made: one to the orientation (left vs. right) of the stimulus and one to its color (green vs. blue).

Our main aim was to test whether masked blindsight occurs without any subjective awareness of the presence of the stimulus. That would be supported if the orientation or color could be discriminated better than expected by chance in trials in which the observer consistently denies having had any awareness of the presence of the stimuli (i.e., reports having seen “nothing” to both orientation and color). On the other hand, it remains possible that completely unconscious stimuli do not elicit any unconsciously guided responses, but unconscious processing of visual features in masked blindsight depends on awareness of some other, *task-irrelevant feature*. The common finding that accuracy exceeds chance-level when “a glimpse of something that cannot be identified” is seen (Ramsøy & Overgaard, 2004) suggests that unconscious guided responses may depend on awareness of some irrelevant feature and hence rely on the same processing pathways that are responsible for conscious perception. Thus, if performance exceeds chance-level in discriminating the *task-relevant feature* (e.g., orientation in orientation discrimination task) without any awareness of the relevant feature only when awareness of at least something task-irrelevant (e.g., in response to color) is reported, the results would support only Type 2-like masked blindsight.

The requirement to respond to two features in each trial is interesting also, because different features of objects, such as orientation, shape, and color, are initially processed in specialized cortical regions (Livingstone & Hubel, 1988), but in visual awareness they appear as bound, phenomenally unified entities (Revonsuo, 1999). Traditionally a tight relationship between consciousness and binding has been assumed, but more recently it has been proposed that some kind of fragile visual binding can occur without consciousness (Humphreys, 2016; Lin & He, 2009). It is unclear how processing of the task-relevant and -irrelevant stimulus features are related to each other when no awareness is reported: if one of the features is correctly discriminated without awareness, does that predict accuracy in discriminating the other subjectively unconscious feature of the same stimulus? If not, that would imply that the features were processed separately without binding the shape and color. In addition, we used two types of target stimuli (Gabor gratings and arrow-shaped stimuli) to test the idea (Song & Yao, 2016) whether low level features (i.e., orientation of grating) would be associated with stronger masked blindsight than higher level features such as a shape (i.e., orientation of arrow shape) which is composed of the parts of the gratings and hence requires binding of features within visual domain.

2. Experiment 1

2.1. Method

2.1.1. Participants.

Forty healthy students (4 males) from the University of Turku participated. Their mean age was 25.5 years, ranging from 19 to 52 years, and they had normal or corrected to normal vision. Four of the participants reported in every trial that they saw at least a glimpse of something, also in catch trials, which suggests that they did not follow the instructions. As Type 1 masked blindsight is impossible to assess in these participants, they were replaced with new ones. This experiment, as well as Experiments 2 and 3, were conducted in accordance with the Declaration of Helsinki and with the understanding and conscious consent of each participant.

2.1.2. Apparatus and stimuli.

The stimuli were presented on 19 -inch CRT screen with 1024x768 pixel resolution and 85 Hz screen refresh rate. E-Prime 2.0 software (Psychology Software Tools, Inc.) controlled stimulus presentation and recorded responses.

The stimuli were Gabor gratings and arrow figures (Figure 1A). The Gabor stimuli were green (RGB 128, 195, 128) or blue (RGB 128, 128, 255) sinusoidal gratings (1.4 cycles/degree) , which were tilted 45° left or right, and subtended 5.0° of visual angle from 40 cm viewing distance. The luminance, measured from the screen, was 41 cd/m^2 for green and 28 cd/m^2 for blue. The RGB values were selected on the basis of a pilot study (n = 5 participants) in which the RGB values varied. It showed that with the selected values, the green and blue color were equally difficult to discriminate in spite of the different luminance levels. The arrow stimuli were created from the Gabors by cutting them half horizontally, reversing vertically the upper halves into their mirror images, and then creating the lower parts of the arrows from them.

The masks were created by first blurring a colorful grid, taken from a previous study's Mondrian masks (Koivisto & Grassini, 2018), after which the blurred image was superimposed with transparent grey left and right tilted (45°) Gabors with the same size and spatial frequency as the stimuli. The resulting image was rotated 90, 180, and 270 degrees so that four different masks resulted.

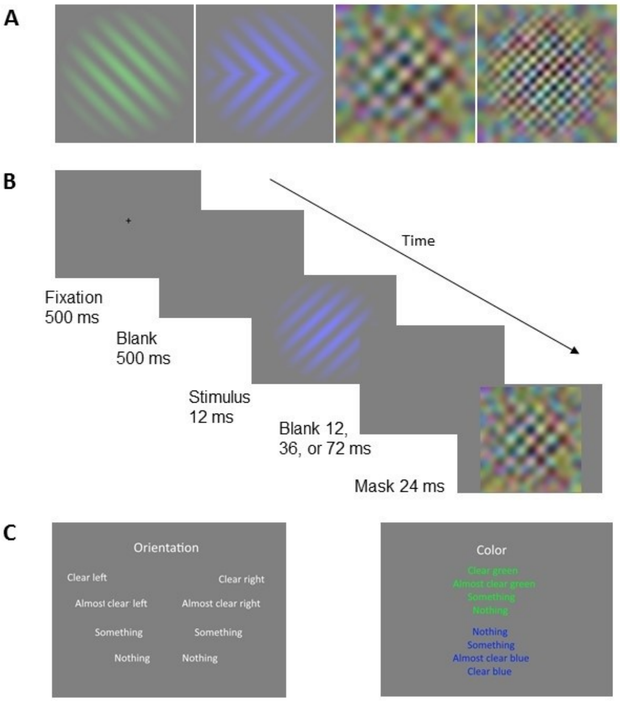

Figure 1. A) From left to right, examples of the gabor stimulus, arrow stimulus, the low density mask in Experiment 1, and the high density mask in Experiment 2. B) The sequence of stimulation. C) The mask was followed by response screens for orientation and color (in counterbalanced order); the participants used computer mouse to select one of the response alternatives in each response screen.

2.1.3. Procedure.

Each trial began with a presentation of the fixation point in the center of the gray background (20 cd/m²) for 500 ms (Figure 1B). It was followed by blank gray screen for 500 ms, after which a randomly chosen stimulus (or blank screen in catch trials) was presented for 12 ms (i.e., one screen refresh). The stimulus was followed by a randomly chosen mask, randomly after 1, 3, or 6 screen refreshes for 24 ms (i.e., 2 screen refreshes), so that the stimulus-onset asynchrony (SOA) was 24, 48, or 83 ms. The purpose of the manipulation of SOA was to induce variability on awareness and performance. After 1 sec had elapsed from the offset of the mask, the first response display (for orientation or color response) was presented and it remained on the screen until the participant had made a response (Figure 1C). The second response display (for color or orientation response) followed until the second response was made.

The participants had to make two responses to the stimulus, concerning its orientation and its color. For the orientation response, the response screen contained on the left side options for the PAS ratings (Ramsøy & Overgaard, 2004) ”nothing”, ”something”, ”almost clear left”, and ”clear left”, whereas the right side options included boxes for ”nothing”, ”something”, ”almost clear right”, and ”clear right”. The participant had to select the left or right side on the basis of the perceived orientation of the stimulus, or when nothing or only a glimpse of something was seen they had to guess the orientation and correspondingly select either the left or right side “nothing” or “something” option. Thus, both the forced-choice orientation discrimination and the subjective PAS rating were given with a single mouse click. In the color response screen, the boxes were arranged vertically. Up to down direction, the alternatives were for green responses ”clear green”, ”almost clear green”, ”something”, and ”nothing”, written with green font, and ”nothing”, ”something”, ”almost clear blue”, and ”clear blue” for blue alternatives in blue font. The participants had to select the green or blue color option, even if they perceived nothing or only a glimpse of something. Thus, the forced-choice discrimination and subjective rating were indicated with a single mouse click. It was stressed that the “nothing” option meant always that they did not perceive the presence of the stimulus at all, whereas the “something” option meant that they had perceived something but they did not have any perception of the feature in question.

Half of the participants made the orientation response first, followed by the color response, whereas the other half made them in the reversed order. The participants performed two task blocks, with one block involving the Gabors as stimuli and the other one involving the arrow stimuli. The participants were informed about the nature of the stimuli (Gabor or arrow) in the beginning of each stimulus block by showing pictures of them in free vision. The order of the blocks was counterbalanced across participants. Each block included 180 stimulus-present trials and 20 catch trials, and was preceded by 20 practice trials.

2.1.4. Data analyses.

The results were analysed with R statistical software 3.5.0 (R Core Team, 2018), using packages lme4 (Bates, Mächler, Bolker, & Walker, 2015), sjPlot 2.4.1. (Lüdecke, 2019), and Psycho 0.4.0 (Makowski, 2018). The signal detection analyses of awareness were performed with analyses of variance (ANOVAs) with Feature (orientation vs. color) and Stimulus (Gabor vs. arrow) as within-participant variables.

The analyses of accuracy in trials in which the participants reported not having seen the stimulus feature were conducted on single trials with generalized linear mixed-effect logistic models (Bates, Mächler, Bolker, & Walker, 2015); note that in these models the intercept and beta values are expressed in terms of log odds ratio (e.g., the beta value 0 for the intercept means that accuracy was at chance level). The explanatory power of the models is expressed as conditional and marginal R2 (Nakagawa & Shielzeth, 2013). The independent (i.e., fixed) variables were coded as factors, and SOA was coded as ordered factor, which allowed trend analyses. One should also note that it was not possible to include all, or even most of the independent variables (e.g., feature, awareness of orientation, awareness of color, orientation accuracy, color accuracy, stimulus type, SOA) with all their levels in single model, as some of the variables show collinearity or there are too few trials per cell and the model does not converge. Therefore, accuracy was analyzed with more specific models focusing directly on the research questions specified in the introduction. Participant served as a random variable in each model; the fixed variables in the models will be described in detail below in the context of each analysis. To account for the possible effect of response order (orientation response before the color response vs. color response before the orientation responses) we conducted each model in three ways: without the response order as fixed effect, with the response order as fixed effect, and with the response order and its' interactions as fixed effects. These models were then compared with the anova function in R, and if no statistically significant differences between the models were detected, the simples model (without response order as fixed effect) is reported. If the a model with response order or response order with interactions as fixed effects fitted the data better than the simplest model, we report the model with the best fit based on Bayesian information criterion (BIC) value.

2.2. Results

2.2.1. Awareness.

The distribution of awareness ratings for orientation and color on PAS in stimulus-present trials is illustrated in Figures 2A and 2B. It reveals that in most of the trials the PAS rating agree for the features orientation and color. For example, when the rating for orientation was "nothing", also the rating for color was "nothing" in most of the trials. The same is true for all the other PAS ratings. However, there is also interesting variability between the features. For example, in subsets of trials the rating for color was higher than that for orientation, and vice versa.

We performed a signal detection analysis on awareness by defining PAS ratings "something", "almost clear", and "clear" in response to stimulus-present trials as hits. In these trials, the participants reported having detected the presence of the stimulus. False alarms were defined as PAS ratings "something", "almost clear", and "clear" in response to catch (stimulus-absent) trials; here the participants reported that they had detected the stimulus although no stimulus was presented. A Stimulus (2: Gabor vs. arrow) x Feature (2: orientation vs. color) repeated-measures analysis of variance (ANOVA) on the discrimination index (*d'*) suggested that that the *d'* (Figure 2C) was higher for color than for orientation, F(1,39) = 4.61, p = .038, $\eta_p^2 = .106$. However, after sequential Bonferroni correction of the alpha level, the p-value was higher than the corrected alpha level (.0167) (for multiple-comparison corrections in exploratory ANOVAs, see Cramer et al., 2016). Stimulus did not have an effect, F(1,39) = 1.78, p = .190, $\eta_p^2 = .044$, and the two-way interaction was not statistically significant, F(1,39) = 0.49, p = .488, $\eta_p^2 = .012$. Analysis of the response criterion *c* (Figure 2D) did not find any statistically significant effects; Feature: F(1,39) = 2.23, p = .144, $\eta_p^2 = .054$; Stimulus: F(1,39) = 0.91, p = .346, $\eta_p^2 = .023$; Feature x Stimulus: F(1,39) = 3.02, p = .090, $\eta_p^2 = .072$. The criterion did not differ from zero, F(1,39) = 2.23, p = .144, $\eta_p^2 = .054$, suggesting that the observers used a neutral criterion.

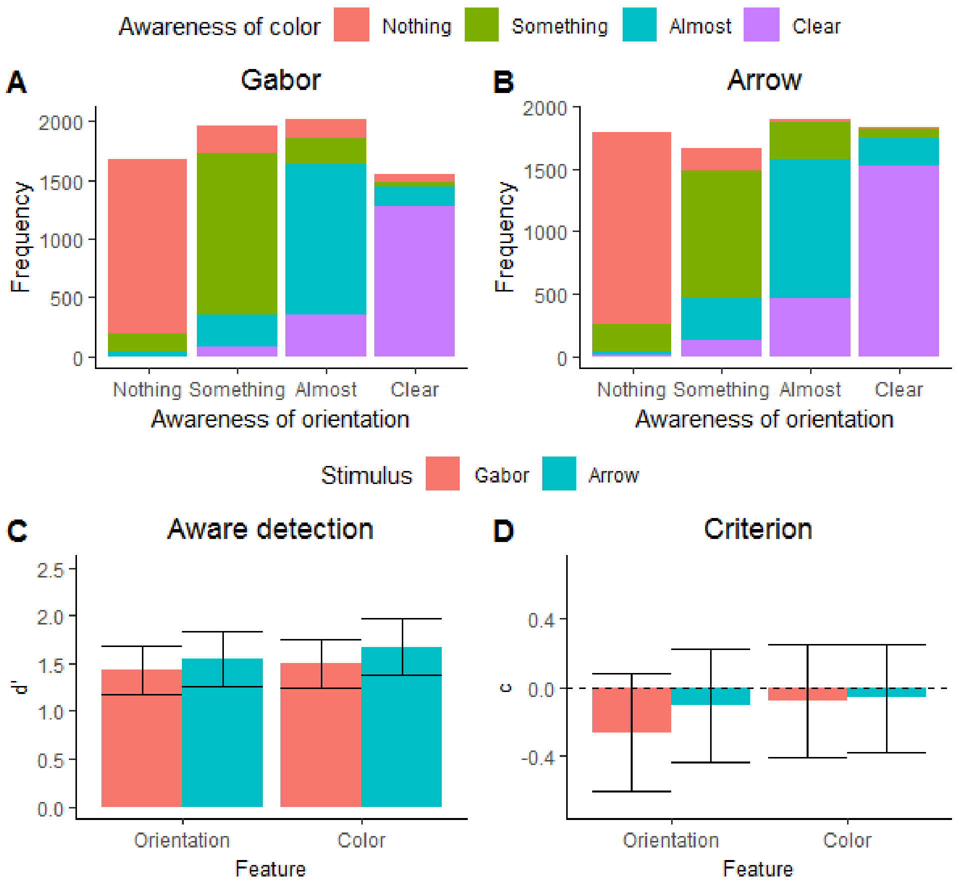

Figure 2. Awareness in Experiment 1. The distribution of trials as a function of awareness ratings in Perceptual Awareness Scale (PAS) for orientation and color of (A) Gabor and (B) arrow stimuli. (C) Aware detection of the presence of stimulus, operationalized as *d′*, and (D) the criterion *c* to report having detected the stimulus. Error bars represent 95% CIs.

2.2.2. Orientation

The observed accuracy in discriminating the orientation of Gabor and arrow stimuli is presented in Figures 3A and 3B as a function of awareness of orientation and color, rated with Perceptual Awareness Scale (PAS). Linear mixed effects logistic model for accuracy in single trials with PAS as a fixed variable showed that accuracy of discriminating orientation increased linearly as a function of awareness of orientation in PAS (beta = 1.58, SD = 0.05, z = 31.52, p < .001). The model with SOA as fixed variable showed that accuracy increased linearly as a function of SOA, beta = 1.05, SE = 0.12, Z = 9.06, p < .001 (Supplementary materials A). With accuracy of color discrimination as a fixed variable, across pooled levels of awareness ratings, accuracy of color discrimination predicted accuracy in discriminating the orientation in the same trial (beta = 0.62, SD = 0.05, z = 13.58, p < .001). In the following critical statistical analyses, we focused on trials in which the participants reported in response to the orientation task that that they were not aware of the presence of any stimulus (PAS = “nothing”, Type 1 masked blindsight) or they were aware that something was presented but they did not see what it was (PAS = “something”, Type 2-like masked blindsight).

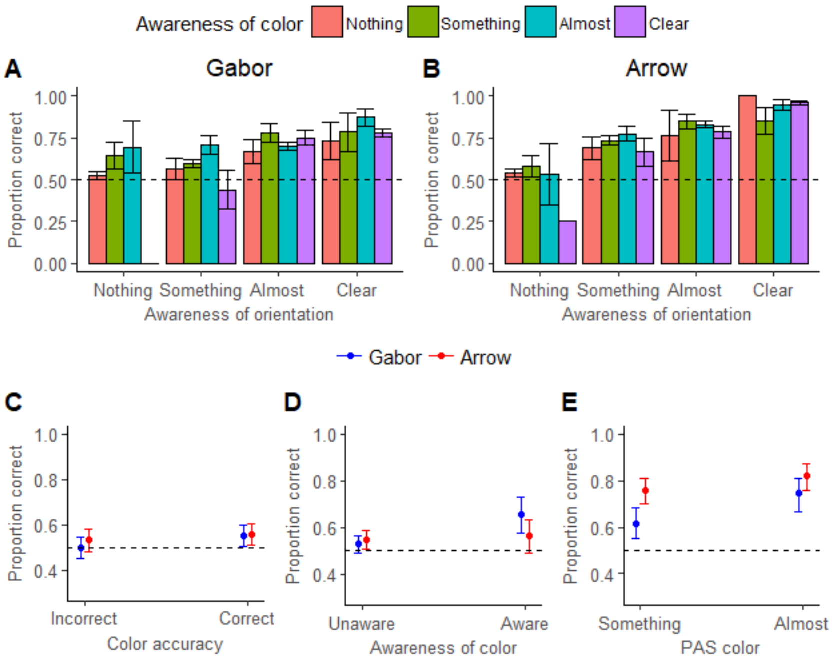

Figure 3. Observed accuracy in discriminating the orientation of (A) Gabor and (B) arrow stimuli as a function of reported awareness of orientation and color in Perceptual Awareness Scale (PAS) in Experiment 1. Modeled accuracy in trials without reported awareness of orientation (“nothing”) as a function of (C) accuracy in discrimination of color when also awareness of color was rated as “nothing”, and as a function of (D) awareness of color. (D) Modeled accuracy in discriminating orientation when glimpse of something was reported as a function the PAS rating for color. Error bars[1] represent 95% CI.

First, we selected only trials in which awareness of both the orientation and the color was rated as “nothing” in PAS scale (Figure 3C). We studied whether or not accuracy in color discrimination predicted accuracy of orientation discrimination in these trials with a generalized linear mixed-effects logistic model, in which the accuracy of color discrimination, stimulus type (Gabor vs. arrow), and their interaction were fixed variables. Random intercept for participants was included as a random variable. The overall model predicting accuracy in orientation discrimination (accuracy ~ Color accuracy * Stimulus + (1 | participant)) had an explanatory power (conditional R2) of 0.20%, in which the fixed effects' part was 0.24% (marginal R2). The model's intercept was at 0 (SE = 0.098, 95% CI [-0.19, 0.19]), that is, exactly at the chance level of 50.0% correct, 95% CI[45.2, 54.7], indicating that the orientation of Gabor was not discriminated better than chance (z = -0.009, p =

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[1] Note that two bars in “nothing/clearly seen” conditions, one in Figure 3A and one in 3B, lack error bars. These conditions included only few trials and the CIs were so large that they did not fit the scale in y-axis.

.993) when the color was discriminated incorrectly. However, correct color discrimination increased the accuracy of orientation discrimination to 55.3%, 95% CI [50.6, 59.8] (beta = 0.21, SE = 0.11, 95% CI [0.0040, 0.42], z = 2.00, p = .046. The effect of Stimulus (beta = 0.13, SE = 0.11, 95% CI [-0.087, 0.34], z = 1.17, p = .243) and the interaction between Color discrimination and Stimulus (beta = -0.11, SE = 0.15, 95% CI [-0.40, 0.19], z = -0.71, p = .478) were not significant. In summary, the discrimination of orientation without any reported awareness of the stimulus did not differ from the 50% chance level in trials in which the color discrimination was performed incorrectly. However, orientation could be discriminated better than expected by chance when the color (rated as "nothing" seen) was discriminated correctly; a model with SOA as fixed variable suggested that this result did not depend on SOA (Supplementary materials B).

Second, we studied whether subjective awareness of task-irrelevant feature (i.e., color) predicted accuracy in discriminating the orientation without awareness of orientation (Figure 3D). Only trials in which the participants' report of awareness for orientation was "nothing" were selected; the report of awareness in response to color was coded as a two-level factor: unaware (PAS rating "nothing") or aware (PAS ratings "something" or "almost clear"). The trials with "clear" rating for color were excluded, because they were rare (Fig. 2) and because responding to the orientation with "nothing" and to the color of the same stimulus with "clear" is contradictory and most probably reflects erroneous button presses due to attentional or other failures. Generalized linear mixed-effects logistic model was fitted for accuracy of the orientation discrimination with awareness of color, stimulus, and their interaction as fixed variables and the participant as a random variable (accuracy ~ color awareness*stimulus + (1 | participant)). The overall model (n = 3433 trials) had an explanatory power (conditional R2) of 0.34%, in which the fixed effects' part was 0.41% (marginal R2). The model's intercept was at 0.11 (SE = 0.080, 95% CI [-0.048, 0.27]), corresponding to 52.7% accuracy (95% CI [48.8, 56.6]), and it did not differ from the chance level, p = .169. This finding indicates that the orientation of Gabor could not be discriminated better than 50% correct when awareness of both orientation and color was rated to be “nothing”. However, awareness of color significantly increased accuracy (beta = 0.54, SE = 0.18, 95% CI [0.20, 0.90], z = 3.05, p = .002). When the observers were aware of the color, their accuracy was 65.8% correct (95% CI [57.5, 73.1]). The effect of stimulus was not significant (beta = 0.073, SE = 0.075, 95% CI [-0.075, 0.22], z = 0.97, p = .333). However, the interaction (Color awareness * Stimulus) was significant (beta = -0.48, SE = 0.22, 95% CI [-0.92, -0.043], z = -2.14, p = .032), indicating that the effect of color awareness was restricted to Gabor stimuli and did not occur for arrow stimuli. These findings refer to Type 2-like masked blindsight, which is not associated with complete unawareness of the stimulus but awareness of at least something that was presented (i.e., color).

The third analysis (Figure 3E) focused specifically on Type 2-like masked blindsight for orientation, involving the trials in which awareness of orientation was rated as “something” (i.e., “I saw a glimpse of something but did not see the orientation”). Stimulus and Awareness of color (“something” vs. “almost clear”) were fixed variables. The overall model (accuracy ~ Awareness of color * Stimulus + (1 | participant)) (n = 3016) had an explanatory power (conditional R2) of 2.77%, in which the fixed effects' part was 3.67% (marginal R2). The model's intercept was at 0.48 (SE = 0.14, 95% CI [0.20, 0.77]), which corresponds to 61.8% correct (95% CI [55.0, 68.1]), and which is significantly higher than expected by chance, z = 3.35, p < .001. In other words, orientation of Gabor could be discriminated when the observers were aware that something was presented but they reported that they did not know its’ orientation. Within this model, the effect of awareness of color was significant (beta = 0.59, SE = 0.16, 95% CI [0.27, 0.91], z = 3.61, p < .001), suggesting that orientation discrimination improved as reported awareness of color increased. The effect of Stimulus was significant (beta = 0.67, SE = 0.098, 95% CI [0.48, 0.87], z = 6.86, p < .001): the orientation of arrow was discriminated more accurately than that of Gabor, and this effect did not interact with awareness of color (beta = -0.22, SE = 0.22, 95% CI [-0.65, 0.21], z = -0.99, p = .323).

2.2.3. Color

Observed data on color discriminations as a function of awareness is presented in Figures 4A and 4B. Accuracy of discriminating color increased linearly as a function of awareness of color (beta = 3.19, SE = 0.11, z = 28.87, p < .001); the linear increase was steeper than that observed for discrimination of orientation, beta = 1.84, SD = 0.12, z = 15.75, p < .001. SOA was linearly associated with accuracy, beta = 1.46, SE = 0.05, z = 32.22 (Supplementary materials C). Across awareness rating levels in PAS, accuracy of orientation discrimination predicted accuracy in discriminating the color in the same trial (beta = 0.62149, SD = 0.04571, z = 13.597, p < .001).

For trials in which awareness of both color and orientation was rated “nothing”, the overall generalized linear mixed-effect logistic model (Figure 4C) predicting accuracy of color discrimination with accuracy of orientation discrimination and stimulus type as fixed factors (accuracy ~ Orientation accuracy * Stimulus + (1 | participant)) had an explanatory power (conditional R2) of 0.20%, in which the fixed effects' part was 0.25% (marginal R2). The model's intercept was at 0.015 (SE = 0.091, 95% CI [-0.16, 0.20])(50.4% correct, 95% CI [45.9, 54.8]) and it did not differ from chance level, z = .175, p = .869. In other words, color of Gabor could not be discriminated correctly, if the orientation in the same trial was discriminated incorrectly. However, accuracy in orientation discrimination increased the accuracy of color discrimination (beta = 0.21, SE = 0.11, 95% CI [0.0039, 0.42], z = 2.00, p = .046)(55.6% correct, 95% CI [51.3, 59.9]): color was discriminated better than expected by chance at the short SOA of 24 ms if also orientation was discriminated accurately (beta = 0.39, SE = 0.11, z = 3.63, p < .001) and this effect tended to be larger as SOA increased, beta = 0.33, SE = 0.20, z = 1.65, p = 0.098 (Supplementary materials D). The effects of Stimulus (beta = 0.12, SE = 0.11, 95% CI [-0.090, 0.33], z = 1.13, p = .260) and the interaction (beta = -0.10, SE = 0.15, 95% CI [-0.39, 0.19], z = -0.68, p = .497) were not significant.

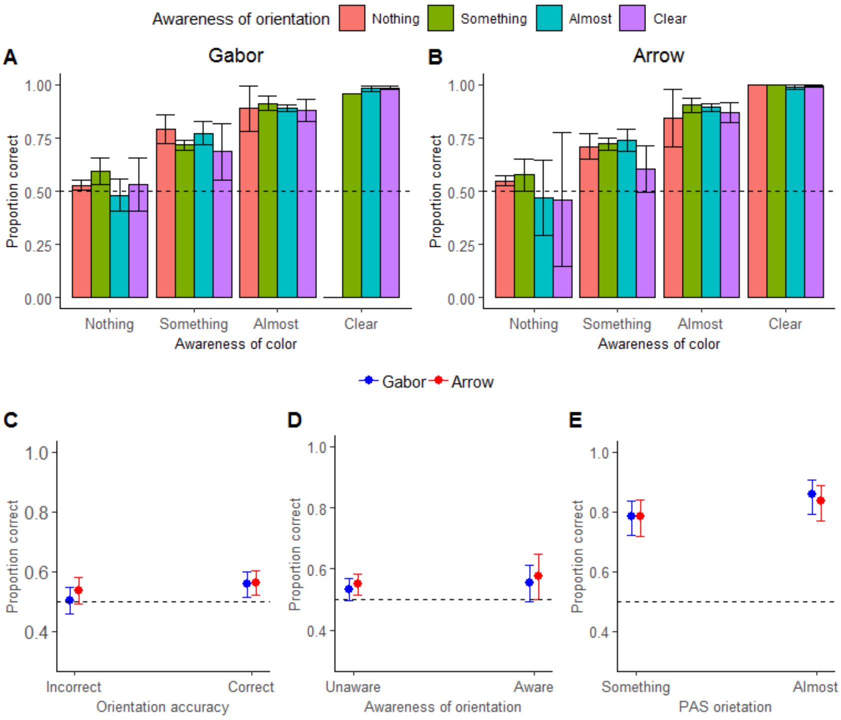

Figure 4. Observed accuracy in discriminating the color of (A) Gabor and (B) arrow stimuli as a function of reported awareness of color and orientation in Perceptual Awareness Scale (PAS) in Experiment 1. Modeled accuracy in trials without reported awareness of color ("nothing") as a function of (C) accuracy in discrimination of orientation when also awareness of orientation was rated as "nothing", and as a function of (D) awareness of orientation. (D) Modeled accuracy in discriminating color when a glimpse of something was reported as a function the PAS rating for orientation. Error bars represent 95% CI.

For analyzing the accuracy of discriminating the color without reported awareness of color, as a function of awareness of orientation, the generalized linear mixed-effect logistic model included trials in which "nothing" was reported to be seen in response to color. Awareness of orientation was coded as a factor (unaware: "nothing", aware: "something" or "almost clear"). The overall model (Figure 4D) predicting accuracy in color discrimination without awareness of color (accuracy ~ Orientation awareness * Stimulus + (1 | participant)) (n = 3641 trials) had an explanatory power (conditional R2) of 0.054%, in which the fixed effects' part was 0.066% (marginal R2). The model's intercept was at 0.13 (SE = 0.075, 95% CI [-0.019, 0.28]), corresponding to 53.2% accuracy (95% CI [49.5, 56.8]), and it did not differ from the chance level, p = .087. Awareness of orientation did not enhance accuracy (beta = 0.085, SE = 0.13, 95% CI [-0.18, 0.35], z = 0.64, p = .523). Accuracy of discriminating the color of the arrow stimulus did not differ from that of Gabor (beta = 0.069, SE =

0.075, 95% CI [-0.078, 0.22], z = 0.92, p = .358). Neither did awareness of orientation and stimulus type interact significantly (beta = 0.023, SE = 0.19, 95% CI [-0.36, 0.40], z = 0.12, p = .907). In summary, there was no Type 1 masked blindsight for color, and awareness of orientation did not improve discrimination of color.

Next, we studied whether Type 2-like masked blindsight appeared for color (Figure 4E), with a model predicting accuracy of color discrimination in trials in which subjective awareness of color was "something" (i.e., "I saw a glimpse of something but did not see the color"). It included Stimulus and Awareness of orientation ("something" vs. "almost clear") as fixed variables (accuracy ~ Awareness of orientation * Stimulus + (1 | participant)). The model had an explanatory power (conditional R2) of 0.42%, in which the fixed effects' part was 0.63% (marginal R2). The model's intercept was at 1.29 (SE = 0.18) (78.3%, 95% CI [0.719, 0.837]), and it was significantly higher than expected by chance, z = 7.28, p < .001. Within this model, awareness of orientation increased accuracy (beta = 0.52, SE = 0.19, z = 2.74, p = .006). The effect of Stimulus (beta = 0, SE = 0.10, z = 0.0032, p = .997) and the interaction (beta = -0.17, SE = 0.25, z = -0.70, p = .484) were not statistically significant, suggesting that the improvement of color discrimination due to increased awareness of orientation was similar for Gabor and arrow stimuli.

2.3. Discussion

Even when complete unawareness of the stimulus was reported for task-relevant feature, sometimes the observers reported awareness of the task-irrelevant feature in the same trial. This finding suggest that the reports of subjective awareness, when "nothing seen" is reported, are not completely reliable; the ratings can vary and be mutually inconsistent even within single trials. This within-trial variation formed the basis for our single-trial data analyses of masked blindsight.

Accuracy in discrimination of one feature correlated with accuracy of discriminating the other feature, either across pooled awareness levels or in trials without any reported awareness (“nothing seen”). The results do provide partial support for Type 1 masked blindsight. Discrimination of orientation or color succeed better than chance level when the observers did not report any awareness (“nothing seen”) for task-relevant and task–irrelevant features but they made the discrimination of the task-irrelevant feature correctly. On the other hand, the analyses in which the task-relevant feature was associated with “nothing seen” report, while the irrelevant feature was rated either as “nothing seen” or “something seen”, did not detect any Type 1 masked blindsight. However, awareness of color was associated with better than chance level discrimination of Gabor’s orientation in trials without any reported awareness of orientation. This pattern of results suggests at best Type 2-like masked blindsight, in which the participant is aware of the stimulus but not of its task-relevant feature.

The pattern of results was different for discrimination of color: awareness of orientation in trials without any reported awareness of color was not associated with better than chance performance in color discrimination. However, discrimination of color, as well as orientation, succeed better than expected by chance when the participants reported awareness of “something” (i.e., that something was presented without any awareness of the orientation or color). This later finding is consistent with the previous studies which show higher than chance level discrimination of variety of features under awareness of “glimpse of something” (Andersen et al., 2019; Lähteenmäki et al., 2015; Ramsøy & Overgaard, 2004).

The results did not support the hypothesis (Song & Yao, 2016) that low level features (i.e., orientation of grating) would be associated with stronger masked blindsight than higher level features such as shape (i.e., orientation of arrow), at least when Type 1 masked blindsight is considered. However, awareness of color was associated with better than chance level performance in discrimination of Gabor grating's orientation but not with that of arrow shape in trials without any reported awareness of orientation, which gives partial support for Type 2-like interpretation of the hypothesis. The difference between the stimulus types could be explained by neurons which code conjunctions of orientation and color in early visual areas (Seymour, Clifford, Logothetis, & Bartels, 2010). Perhaps neurons coding feature conjunctions supported binding the color and orientation of simple gratings more than binding color and shapes at early, preconscious stage of processing, because processing of shapes is more complex and requires also within-modal binding of the line elements into the visual shape.

The models with the order of responding to orientation and color as fixed effect did not explain the results than models without it. There was a potential confound that may explain the different relationships of awareness of color and awareness of orientation with discrimination in trials without any reported awareness of the relevant feature. Namely, processing of color was easier than that of orientation. The signal detection analysis suggested higher awareness of color than awareness of orientation, although after correction for multiple comparisons, this effect did not reach statistical significance. In addition, accuracy of discriminating color increased linearly as a function of awareness of color more steeply than that of orientation. The more demanding processing of orientation may explain why awareness of orientation was not associated with increased color discrimination performance, whereas awareness of color was associated with increased orientation discrimination accuracy. This asymmetric pattern of results may thus be an artifact arising from uncontrolled levels of difficulty between the features. On the other hand, the difference between orientation and color may reflect an intrinsic property of the cognitive system, as there are empirical (Hong & Blake, 2009) and theoretical (Breitmeyer, 2014) grounds suggesting that color enters awareness earlier than shape. In Experiment 2 we shall modify the procedure such that awareness of orientation and of color will be similar.

3. Experiment 2

Experiment 1 found that awareness of color was associated with enhanced discrimination of orientation when the participants reported no awareness of the stimulus' orientation. However, awareness of orientation did not predict discrimination of color in trials without any awareness of color. An uncontrolled aspect in the experiment was that color was easier to process consciously than orientation. Experiment 2 used the same target stimuli but adjusted the masks in a way that was expected to result in better balance between processing the features. In Experiment 1, the mask was constructed by superimposing a colorful grid with transparent grey left and right tilted Gabors with the same size and spatial frequency as the stimuli (1.4 cycles/degree). This created colorful masks displaying left and right oriented grating patterns which consisted of dot-like elements. Masking is known to depend on the similarity of the spatial frequency or spatial density between the target and mask (Drewes, Zhu, & Melcher, 2018; Ishikawa, Shimegi, & Sato, 2006; Legge & Foley, 1980; White & Lorber, 1976). For the masks of Experiment 2, we doubled the spatial frequency of the gratings (2.8 cycles/degree) that were used in creating the masks. Therefore the resulting masks had higher density of grating-like elements than the masks in Experiment 1 (see Fig.1a), reducing the similarity between the gratings in the masks and those in the targets. We assumed that, compared with Experiment 1, this would lower especially masking of orientation, making processing of orientation and color more similar in difficulty.

3.1. Method

3.1.1. Participants.

Forty healthy students (4 males) from the University of Turku participated. Their mean age was 21.6 years, ranging from 19 to 25 years, and they had normal or corrected to normal vision. The experiment was conducted in accordance with the Declaration of Helsinki and with the understanding and written consent of each participant.

3.1.2. Apparatus, stimuli, and procedure.

The apparatus, stimuli, and the procedure were the same as in Experiment 1, with the exception that the masks were different. As in Experiment 1, the masks were generated by superimposing grey left and right tilted Gabors on the colorful grid, but here the spatial frequency of the grey Gabors was twice of that in the Gabor stimuli (1.4 vs. 2.8 cycles/degree). By rotating the mask 90, 180, and 270 degrees we obtained four different mask versions, each with a higher density of the dot-like elements than the masks in Experiment 1 (see Figure 1A). Statistical analyses were performed in the same way as in Experiment 1.

3.2. Results

3.2.1. Awareness

The distribution of ratings of awareness for orientation and color on PAS in stimulus-present trials is illustrated in Figures 5A and 5B. Similar to Experiment 1, in most of the trials the PAS rating for the features orientation and color agreed, but there were also trials in which the ratings disagreed.

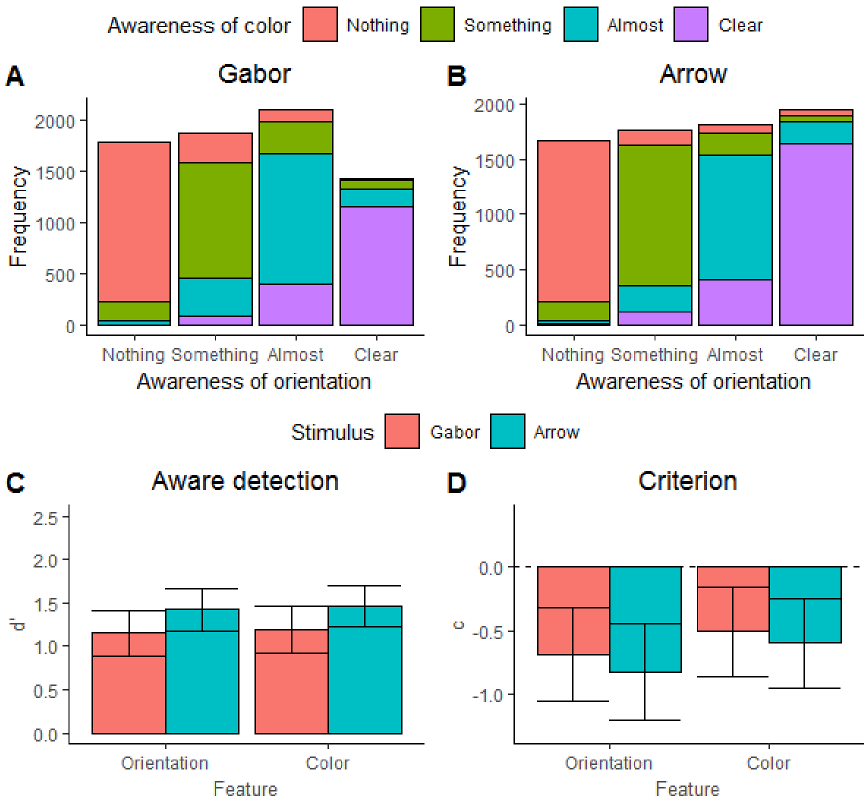

Figure 5. Awareness in Experiment 2. The distribution of trials as a function of awareness ratings in Perceptual Awareness Scale (PAS) for orientation and color of (A) Gabor and (B) arrow stimuli. (C) Aware detection of the presence of stimuli, operationalized as *d'*, and (D) the criterion *c* to report detection of stimuli. Error bars represent 95% CIs.

We analyzed awareness with signal detection theory in the same way as in Experiment 1. The Stimulus (2: Gabor vs. arrow) x Feature (2: orientation vs. color) repeated-measures analysis of variance (ANOVA) on the discrimination index (*d'*) (Figure 5C) with sequential Bonferroni correction did not detect any difference between Gabors and arrows, F(1,39) = 5.15, p = .029, $\eta_p^2 = .117$. No difference was detected between the features F(1,39) = 0.52, p = .475, $\eta_p^2 = .013$, and the Stimulus x Feature interaction did not reach statistical significance, F(1,39) < 0.01, p = 1.00, $\eta_p^2 < .001$. The criterion (*c*) (Figure 5D) was lower than zero, F(1,39) = 15.70, p < .001, $\eta_p^2 = .287$, indicating that the participants used a liberal strategy. The criterion *c* was more liberal in response to orientation than to color, F(1,39) = 6.64, p = .014, $\eta_p^2 = .145$. The stimuli did not differ in *c*, F(1,39) = 1.16, p = .288, $\eta_p^2 = .029$, and the Feature x Stimulus interaction was not statistically significant, F(1,39) = 0.43, p = .518, $\eta_p^2 = .011$. These analyses indicate that awareness did not differ between orientation and color, although the arrows were detected more often than Gabors. The liberal response criterion, which was observed particularly in response to orientation, means that the observers tended to report that they had seen at least something rather than having seen no stimulus.

3.2.2. Orientation

Observed results are displayed in Figures 6A and 6B. Accuracy of orientation discrimination increased linearly as a function of PAS for orientation (beta = 1.57, SD = 0.05, z = 29.59, p < .001), as well as a function of SOA (beta = 0.58, SD = 0.04, z = 16.08, p < .001) (Supplementary materials E). Just like in the previous experiment, discrimination of orientation, pooled across PAS levels, was more likely to be correct, if color was discriminated correctly in the same trial (beta = 0.51, SD = 0.05, z = 10.51).

In the first critical analysis, we predicted the accuracy of orientation discrimination with the accuracy of color discrimination, stimulus, and response order as fixed factors in trials with awareness of both orientation and color rated as “nothing” (n = 2019 trials; Figure 6C). The model (formula = accuracy ~ Color accuracy * Stimulus + Response order+ (1 | participant)) had an explanatory power (conditional R2) of 0.86%, in which the fixed effects' part was 1.05% (marginal R2). The model's intercept was at 0.70 (SE = 0.14, 95% CI [0.42, 0.98]), which corresponds to 67% correct (95% CI [60, 73]) and is significantly above the 50% chance-level, z = 4.905, p < .001. This finding shows that accuracy succeeded better than expected by chance when the orientation response was made before the color response and when the color was discriminated incorrectly. The effects of Stimulus (beta = -0.15, SE = 0.14, 95% CI [-0.42, 0.11], z = -1.12, p = .262), accuracy of color discrimination (beta = -0.16, SE = 0.12, 95% CI [-0.39, 0.066], z = -1.39, p = .164), or their interaction (beta = 0.20, SE = 0.18, 95% CI [-0.16, 0.57], z = 1.11, p = .267) were not statistically significant. However, the response order influenced in such way that accuracy of orientation discrimination was lower when the color was responded to before responding to the orientation (beta = -0.48, SE = 0.13, 95% CI [-0.75, -0.23], z = -3.72, p < .001). Even when color was responded to before orientation, orientation discrimination performance exceeded the chance level (intercept = 0.21, SE = 0.09, z = 2.42, p = 0.015; 55% correct). Thus, here we have evidence supporting the existence of Type 1 masked blindsight for orientation and simple shape. Discrimination of orientation without any reported awareness did not depend on the accuracy of discriminating color. To verify that the Type 1 masked blindsight did not depend on SOA, we collapsed the stimulus types and analysed with SOA as a fixed variable the incorrect color discrimination trials which were associated with no reported awareness of orientation and color. The analysis did not reveal any effects for SOA (see Supplementary materials F).

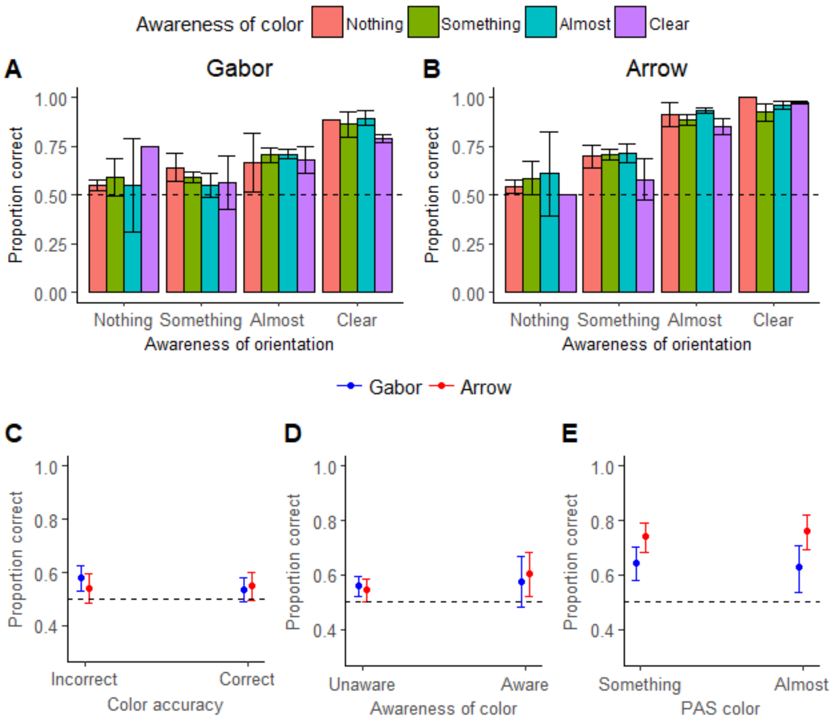

Figure 6. Observed accuracy in discriminating the orientation of (A) Gabor and (B) arrow stimuli as a function of reported awareness of orientation and color in Perceptual Awareness Scale (PAS) in Experiment 2. Modeled accuracy in trials without reported awareness of orientation ("nothing") as a function of (C) accuracy in discrimination of color when also awareness of color was rated as "nothing", and as a function of (D) awareness of color. (D) Modeled accuracy in discriminating orientation when glimpse of something was reported as a function the PAS rating for color. Error bars represent 95% CI.

The next generalized linear mixed-effects model (Figure 6D) predicted accuracy in discriminating orientation without awareness of orientation ("nothing") with awareness of color, stimulus type, and response order (formula = accuracy ~ Awareness of color * Stimulus + Response order + (1 | participant)) (n = 2300 trials). The model had an explanatory power (conditional R2) of 0.63%, in which the fixed effects' part was 0.78% (marginal R2). The model's intercept was at 0.55 (SE = 0.13, 95% CI [0.30, 0.81]). In other words, when the orientation response was made before the color response and "nothing seen" was reported for both orientation and color, discrimination of orientation succeeded with accuracy of 63.4% (95% CI [57.4, 69.2]), which was higher than the 50 % chance-level, z = 4.29, p < .001. However, response order had a significant effect (beta = -0.41, SE = 0.13, 95% CI [-0.68, -0.15], z = -3.05, p = .002). When color was responded to before orientation, accuracy decreased to 54% correct (95% CI [50, 57]), but was still higher than the chance-level (Intercept = 0.14, SE = 0.07, z = 1.97, p = 0.049). The effects of Stimulus (beta = -0.055, SE = 0.094, 95% CI [-0.24, 0.13], z = -0.58, p = .559), Awareness of color (beta = -0.025, SE = 0.20, 95% CI [-0.43, 0.38], z = -0.12, p = .903), and their interaction (beta = 0.28, SE = 0.28, 95% CI [-0.26, 0.82], z = 1.00, p = .316) was not statistically significant. These results converge with the previous model in providing evidence for the existence of Type 1 masked blindsight.

Next, we studied Type 2-like masked blindsight, in other words, we tested whether the participants were able to discriminate the orientation when they subjectively reported that they saw a glimpse of something but did not see the orientation (Figure 6E). The overall model (n = 3000) predicting accuracy (formula = accuracy ~ Awareness of color * Stimulus + (1 | Participant)) had an explanatory power (conditional R2) of 1.22%, in which the fixed effects' part was 1.60% (marginal R2). The model's intercept was at 0.58 (SE = 0.14, 95% CI [0.31, 0.87]), corresponding to 64.2% accuracy (95% CI [0.578, 0.702]) which is higher than expected by chance, z = 4.24, p < .001. Within this model, the effect of awareness of color was not significant (beta = -0.068, SE = 0.16, 95% CI [-0.38, 0.24], z = -0.43, p = .669). The orientation of the arrow stimulus was discriminated better than that of Gabor at intercept (beta = 0.46, SE = 0.093, 95% CI [0.28, 0.64], z = 4.92, p < .001). The Stimulus and Awareness of color did not interact (beta = 0.19, SE = 0.22, 95% CI [-0.24, 0.61], z = 0.86, p = .390), suggesting that both stimulus types were similarly uninfluenced by awareness of color.

3.2.3. Color

Accuracy of color discrimination increased as a function of PAS rating of color (beta = 3.11, SD = 0.09, z = 33.36, p < .001)(Figure 7A and 7B). The linear increase was steeper for color than for orientation (beta = 1.45, SD = 0.10, z = 14.48, p < .001). Accuracy increased linearly as a function of SOA (beta = 1.35, SE = 0.05, z = 29.51, p < .001)(Supplementary materials G). Across all stimulus-present trials, accuracy in discriminating the orientation predicted accuracy in discriminating the color in the same trial (beta = 0.51, SD = 0.04, z = 10.518, p < .001).

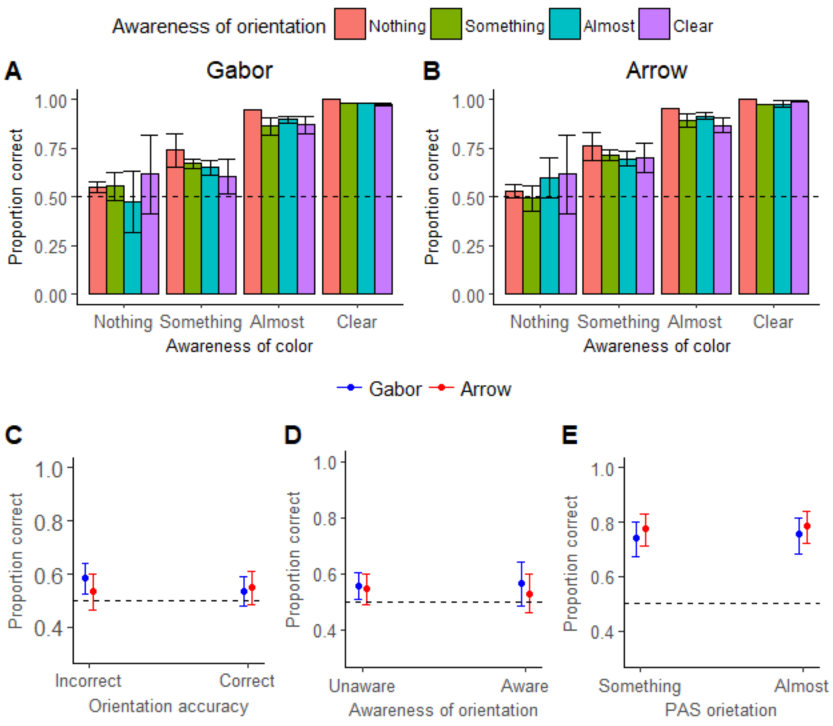

Figure 7. Observed accuracy in discriminating the color of (A) Gabor and (B) arrow stimuli as a function of reported awareness of color and orientation in Perceptual Awareness Scale (PAS) in Experiment 1. Modeled accuracy in trials without reported awareness of color ("nothing") as a function of (C) accuracy in discrimination of orientation when also awareness of orientation was

rated as “nothing”, and as a function of (D) awareness of orientation. (D) Modeled accuracy in discriminating color when a glimpse of something was reported as a function the PAS rating for orientation. Error bars represent 95% CI.

In trials without any awareness of either feature (rating = “nothing”), accuracy of color discrimination was first predicted with accuracy of orientation discrimination. The generalized linear mixed-effects model (Figure 7C) involved accuracy of orientation discrimination and stimulus as fixed factors (formula = accuracy ~ Orientation accuracy * Stimulus + (1 | participant)). It had an explanatory power (conditional R2) of 0.18%, in which the fixed effects' part was 0.22% (marginal R2). The model's intercept was at 0.34 (SE = 0.12, 95% CI [0.10, 0.59]), which corresponded to 58.5% correct (95% CI [52.5, 64.2]) and was higher than the chance level, z = 2.78, p = .005. The effects of Orientation accuracy (beta = -0.21, SE = 0.12, 95% CI [-0.44, 0.027], z = -1.73, p = 0.083), Stimulus (beta = -0.21, SE = 0.14, 95% CI [-0.48, 0.068], z = -1.47, p = .041), and their interaction (beta = 0.27, SE = 0.19, 95% CI [-0.097, 0.64], z = 1.44, p = .150) were not statistically significant. These findings support Type 1 masked blindsight for color. The model with SOA as fixed factor on the trials with incorrect orientation discrimination and without awareness of color and orientation revealed a quadratic trend (beta = 0.35, SE = 0.15, z = 2.33, p = .020) (Supplementary materials H). Accuracy of color discrimination was higher than chance-level at the short 24 ms and long 83 ms SOAs. There was a drop in the estimated mean accuracy at the intermediate 48 ms SOA, as compared with the accuracy at the long SOA. These results indicate that the higher than chance-level performance was not restricted to the shortest SOA.

The overall model (Figure 7D) predicting accuracy of discriminating the color without color awareness with awareness of orientation (formula = accuracy ~ Awareness of orientation * Stimulus + (1 | participant)) had an explanatory power (conditional R2) of 0.041%, in which the fixed effects' part was 0.050% (marginal R2). The model's intercept was at 0.23 (SE = 0.10, 95% CI [0.026, 0.43]), showing that accuracy (55.7% correct, 95% CI [50.7, 60.5]) was higher than expected by chance, z =

2.24, p = .025. None of the fixed effects was statistically significant (Awareness of orientation: beta = 0.025, SE = 0.17, 95% CI [-0.30, 0.36], z = 0.15, p = .881; Stimulus: beta = -0.048, SE = 0.096, 95% CI [-0.24, 0.14], z = -0.50, p = .615; interaction: beta = -0.094, SE = 0.21, 95% CI [-0.51, 0.32], z = -0.45, p = .656). In short, the participants showed Type 1 masked blindsight for color.

The model predicting accuracy of color discrimination in trials in which subjective awareness of color was “something” (i.e., “I saw a glimpse of something but did not see the color”) included Stimulus and Awareness of orientation (“something” vs. “almost clear”) as fixed variables (Figure 7E). The overall model (n = 3593) (formula = accuracy ~ Awareness of orientation * Stimulus + (1 | participant)) had an explanatory power (conditional R2) of 0.18%, in which the fixed effects' part was 0.25% (marginal R2). The model's intercept was at 1.05 (SE = 0.17, 95% CI [0.72, 1.39])(i.e., 74.1% correct, 95% CI [67.3, 79.9]) and it was significantly higher than the chance level, z = 6.29, p < .001. Within this model, the effect of Stimulus was significant (beta = 0.19, SE = 0.10, 95% CI [0.01, 0.38], z = 2.03, p = .043), showing that the color of the arrow was discriminated better than that of Gabor. Awareness of orientation did not have any effect (beta = 0.07, SE = 0.12, 95% CI [-0.17, 0.31], z = 0.56, p = .574) and it did not interact with stimulus type (beta = -0.0081, SE = 0.17, 95% CI [-0.33, 0.32], z = -0.049, p = .961).

3.3. Comparison of the results of Experiments 1 and 2

Analysis of the results of Experiment 2 produced different outcomes as compared with those of Experiment 1. Although in Experiment 2 discrimination of color still linearly increased more steeply than that of color as a function of rated awareness, the difference was reduced as compared with that in Experiment 1 (Experiment*Feature*PAS: beta = -0.38, SD = 0.15, z = -2.51, p = .012). The effect sizes and differences were small in the conditions with limited awareness. Therefore, to test which of the effects and differences between experiments were statistically reliable, we run the generalized linear logistic mixed-effects models focusing on trials without any reported awareness of the task-relevant feature, this time including the data from both experiments with Experiment as a fixed variable.

3.3.1. Orientation

The model on accuracy of orientation discrimination in trials in which both orientation and color was rated as “nothing” (Figure 8A) revealed an effect for Experiment, beta = 0.36, SE = 0.16, 95% CI [0.0061, 0.38], z = -2.53, p = .011, confirming that accuracy in Experiment 2 was higher than in Experiment 1 at intercept (rating “nothing” for orientation and color, incorrect color discrimination). In addition, the effect of Color accuracy was significant, beta = 0.21, SE = 0.11, z = 2.01, p = 0.045, showing again the finding that in Experiment 1 Color accuracy enhanced accuracy in discriminating the orientation. The Color accuracy x Experiment interaction indicates that color accuracy influenced only in Experiment 1, beta = -0.39, SE = 0.16, CI, z = -2.45, p = 0.014. None of the other effects were statistically significant.

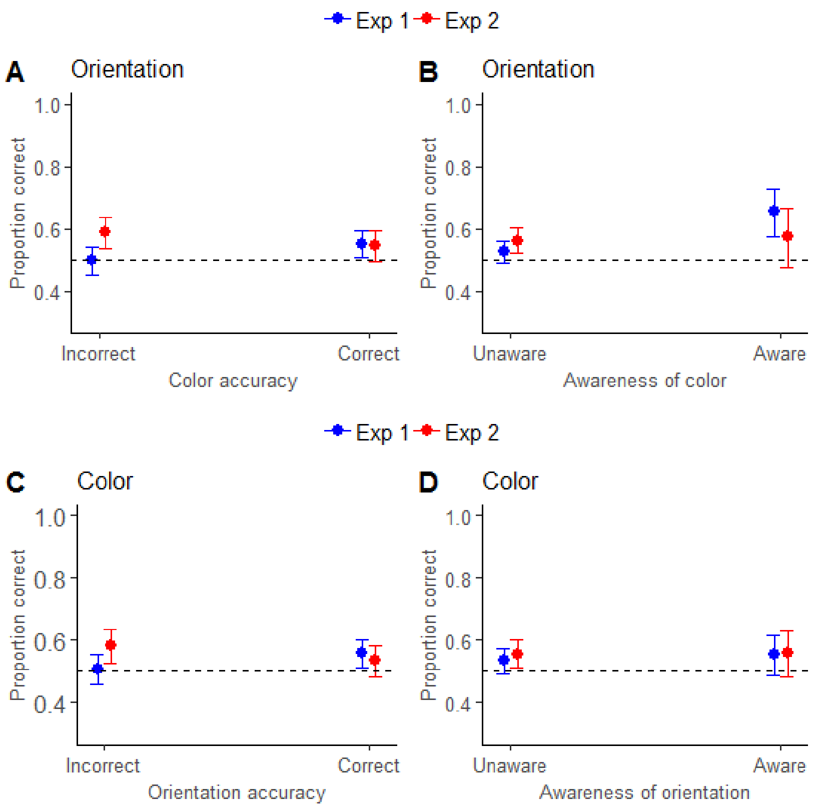

Figure 8. Comparison of accuracy between Experiments 1 and 2 in discrimination of orientation (A and B) and color (C and D) as a function of accuracy or awareness of task-irrelevant feature. The results were pooled across Gabor and arrow stimuli as stimulus type was involved only in one statistically significant effect.

The model on accuracy of orientation discrimination in trials in which orientation was rated as "nothing" and Awareness of color was a fixed variable (Figure 8B) revealed that Awareness of color enhanced discrimination, beta = 0.54, SE = 0.18, z = 3.08, p = 0.002, but this effect differed only marginally significantly between the experiments, beta = -0.50, SE = 0.27, z = -1.82, p = 0.07, although the analysis of Experiment 2 did not detect any effect (section 3.2.2.). The only statistically significant effect that the stimulus type (Gabor vs. arrow) had in the analyses comparing the results of Experiments 1 and 2 was the Awareness of color x Stimulus interaction, which showed that the effect of color awareness was larger for Gabor stimuli than for arrow stimuli in Experiment 1, beta = -0.48, SE = 0.22, z = -2.14, p = 0.032. Although the analysis of Experiment 2 (section 3.2.2.) did not detect any interaction between Awareness of color and Stimulus, the Awareness of color x Stimulus x Experiment interaction was only marginally significant, beta = 0.69, SD = 0.36, z = 1.95, p = .051.

3.3.2. Color

The model on accuracy of color discrimination in trials in which both color and orientation was rated as “nothing” (Figure 8C) revealed an effect for Experiment, beta = 0.31, SE = 0.15, 95% CI [0.01, 0.38], z = -2.12, p = .034, confirming that accuracy in Experiment 2 was higher than in Experiment 1 at intercept (“nothing” rating for orientation and color, incorrect orientation discrimination). Accuracy of color discrimination was higher when orientation was discriminated correctly than when incorrectly in Experiment 1, beta = 0.21, SE = 0.11, Z = 1.97, p = 0.048, but the interaction between orientation accuracy and experiment, beta = -0.41, SE = 0.16, z = -2.58, p = 0.010, suggests that this was not the case in Experiment 2 where accuracy was higher than chance-level and not influenced by accuracy of orientation discrimination (section 3.2.3.).

The last model examining the effects of Awareness of orientation on color discrimination (Figure 8D) did not show any statistically significant effects, which is consistent with the results obtained by the separate analyses of the experiments.

3.4. Discussion

In order to make processing of orientation and color more comparable, Experiment 2 used masks which had higher density/spatial frequency than the masks in Experiment 1. In this experiment subjective awareness of orientation (d’) did not differ from that of color. However, increased awareness of color was associated with larger increase in accuracy as compared with awareness of orientation, but the difference was smaller in Experiment 2 than in Experiment 1.

Experiment 2 did reveal evidence for Type 1 masked blindsight: orientation and color were discriminated above-chance without any reported awareness of the stimulus. Reported awareness of the task-irrelevant feature was not associated with improved discrimination of task-relevant feature. Moreover, discrimination of one of the features did not correlate with discrimination of the other feature when no awareness was reported for either feature: the task-relevant feature could be discriminated correctly even when the task-irrelevant feature was incorrectly discriminated. All these findings were differed from those observed in Experiment 1. However, the differences between the results of the two experiments in discrimination without reported awareness were small and based on comparison of different participant groups. Before discussing these findings any further, we ran Experiment 3 to verify with a within-participant design that the characteristics of mask really can have an effect on discrimination without reported awareness.

4. Experiment 3

The differences between the results of the two experiments in discrimination without reported awareness were slight and based on comparison of different samples of participants (although all came from the same pool). Therefore, we tested in Experiment 3 whether the influence of mask type on discrimination of orientation and color without reported awareness can be replicated with a within-participant design. In addition, Experiments 1 and 2 required discrimination responses and subjective ratings to two features (orientation and color) in each trial, featuring a dual-task procedure that has not been used in previous relevant studies. Therefore in this experiment we tested whether the central results of Experiments 1 and 2 can be generalized to a more typical procedure in which each trial requires responding to only one of the features.

4.1. Method

The participants were 20 exchange students (7 males) studying in University of Turku. Their age was on average 21 years [range: 19–26]. The apparatus and Gabor stimuli were the same as in Experiments 1 and 2. The masks were the low density masks (from Experiment 1) and the high density masks (from Experiment 2).

The stimulus duration and SOAs were the same as in the previous experiments. In the present experiment, the participants responded to different features in separate blocks. In one block, they responded to the orientation of Gabors, in the other one to their color, and each block included both mask types in randomized order; otherwise the procedure was the same as previously. The order of the blocks was counterbalanced across participants. Each block included 168 stimulus-present trials and 20 catch trials (no stimulus), with their presentation order randomized.

4.2. Results

Awareness was analyzed with signal detection measures *d'* and *c*, computed similarly as in previous experiments. The Feature (2) x Mask (2) ANOVA on *d'* did not reveal any statistically significant effects (Figure 9A). The ANOVA on the criterion (*c*) (Figure 9B) found that it was more liberal in response to orientation than to color, F(1,19) = 7.69, p = .012, $\eta_p^2 = .288$. One-sample t-tests showed that the criterion *c* was lower than zero for both orientation, t(19) = -6.21, p < .001, 95% CI [-1.18, -.58], and color, t(19) = -3.60, p = 0.002, 95% CI [-.66, -17], indicating that the participants used a liberal response criterion.

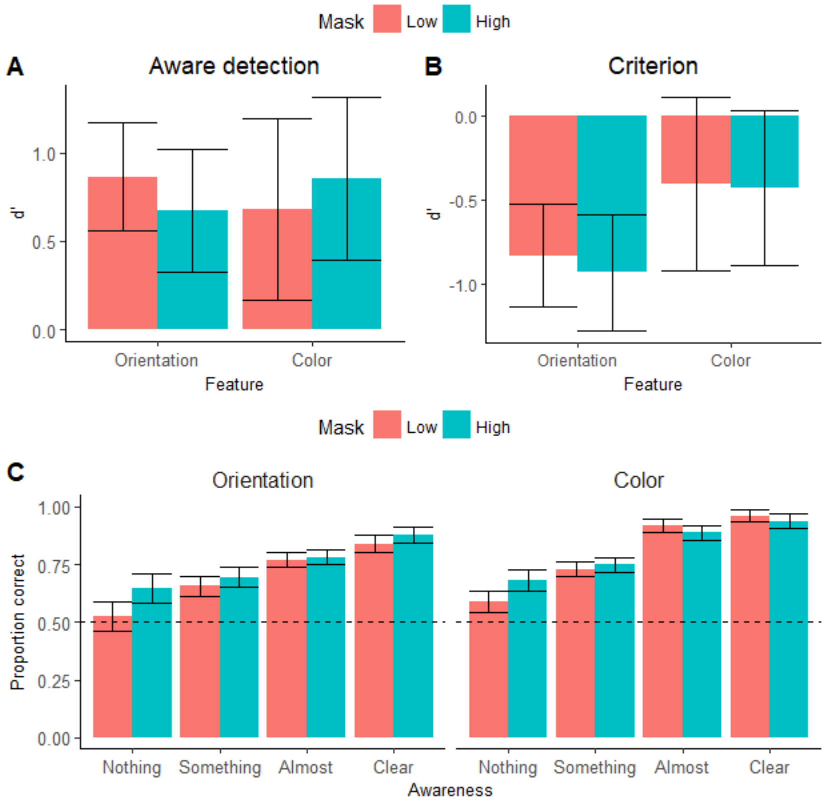

Figure 9. (A) Aware detection of the presence of stimuli, operationalized as d’, and (B) the criterion c to report detection of stimuli. (C) The observed accuracy in discriminating the orientation and color as a function of reported awareness in Perceptual Awareness Scale (PAS). Error bars represent 95% CIs.

It is clear from the observed results in Figure 9C that accuracy in discrimination of orientation and color increased linearly as a function of reported awareness. Accuracy increased also as a function of SOA (Supplementary materials I). The generalized linear mixed-effects model on accuracy including all PAS levels of Awareness, Feature, and Mask as fixed effects did not converge, therefore accuracy was first analyzed by including only the trials with ratings “nothing” (n = 1280 trials), and with Mask and Feature (orientation vs. color) as fixed factors. Participant was a random factor. The model had an explanatory power (conditional R2) of 1.56%, in which the fixed effects' part was 1.97% (marginal R2). The model's intercept (orientation, low density mask) was at 0.064 (SE = 0.16, 95% CI [-0.26, 0.38]), which corresponded to 51.6% correct (95% CI [43.7, 59.5]) and did not differ from the chance level, z = 0.394, p = .694. This indicates that accuracy of orientation discrimination did not differ from chance level with low density masks. Within this model, the high density mask condition resulted in better performance than the low density mask (beta = 0.50, SE = 0.19, 95% CI [0.12, 0.88], z = 2.57, p = .010), and discrimination succeeded better than expected by chance (63.8% correct, 95% CI [55.7, 71.1]). The effect of Feature (beta = 0.27, SE = 0.17, 95% CI [-0.056, 0.60], z = 1.62, p = .104) and the interaction between Mask and Feature (beta = -0.048, SE = 0.25, 95% CI [-0.53, 0.43], z = -0.19, p = .846) were not statistically significant. These results mean that accuracy in both orientation and color discrimination were higher than expected by chance with the high-density mask of Experiment 2, but not with the low-density mask of Experiment 1. The higher than chance-level discrimination of orientation and of color without reported awareness in the high-density mask condition did not depend on SOA (Supplementary materials J).

The corresponding model on trials with awareness reports of “something” had an explanatory power (conditional R2) of 1.80%, in which the fixed effects' part was 2.63% (marginal R2). The model's intercept was at 0.65 (SE = 0.20, z = 3.33, p < .001, 95% CI [0.26, 1.05]), showing higher than chance level performance in discriminating the orientation in the low density mask trials. The performance in the high density masks trials was not significantly different from those with low density masks (beta = 0.13, SE = 0.15, 95% CI [-0.17, 0.44], z = 0.86, p = .390). Color was discriminated better than orientation (beta = 0.70, SE = 0.14, 95% CI [0.42, 0.98], z = 4.86, p < .001), but color and mask type did not interact (beta = -0.083, SE = 0.20, 95% CI [-0.48, 0.31], z = -0.42, p = .677).

4.3. Discussion

Experiment 3 manipulated mask type within participants. Although the mask type did not influence reported awareness of orientation and that of color differently, as was expected on basis of Experiments 1 and 2, it influenced accuracy in trials without any awareness: discrimination of orientation and color succeeded without reported awareness at higher than chance level, but only with the high density mask that was used in Experiment 2. This suggests that the differences between the effects of mask in the comparison of Experiments 1 and 2 were real, not due to the different groups of participants.

When awareness was rated as “something”, orientation and color in both mask conditions were discriminated at higher level than what can be performed simply by guessing, and color in general was discriminated better than orientation. Thus, color discrimination with partial awareness was better than that of orientation. The type of mask did not have any reliable effect on accuracy when the stimulus partially reached awareness.

A new methodological feature in Experiments 1 and 2 was that they required both discrimination responses and subjective ratings to two features (orientation and color) in each trial, introducing a procedure that has not been used in previous relevant studies. Experiment 3 shows that the central results of Experiments 1 and 2 can be generalized to a more typical procedure in which each trial requires responding to one of the features only.

5. General discussion

5.1. Summary of the results

The present study aimed to test whether unconsciously guided action may occur in normal observers in complete absence of reported visual awareness of the target (Type 1 masked blindsight) or whether unconsciously guided action is associated with awareness of some task-irrelevant feature of the target (Type 2-like masked blindsight). The results showed that either Type 1 or Type 2-like masked blindsight can be obtained, depending on masking conditions. Type 1 masked blindsight occurred in Experiment 2 which used masks whose elements’ density did not correspond to that of the stimuli. This effect did not depend on the complexity of the stimulus shape (grating vs. arrow).

Experiment 1 find some evidence for Type 1 masked blindsight with masks whose elements' density corresponded to the spatial frequency of the stimuli, but only if the task-irrelevant feature was discriminated correctly. Experiment 3 manipulated the masks within participants and confirmed that the correspondence between the stimuli and masks indeed is a significant factor contributing to whether Type 1 or Type 2-like masked blindsight occurs. All the experiments, however, indicated Type 2-like masked blindsight, that is, above chance level performance when the participants reported that they were aware of the presence of the stimulus but they were not aware of the task-relevant feature.

5.2. Type 1 masked blindsight

In Type 1 masked blindsight, if it exists, the stimulus evokes a sufficient neuronal network to process some aspects of the stimulus, but the pattern of neuronal activity is not sufficient for any kind of phenomenal experience of the stimulus. Experiments 2 and 3 suggest that orientation, simple shape, and color are able to guide responses without any kind of subjective visual awareness of the target. Color is processed in the ventral pathway through input from parvocellular cells, whereas neurons in the dorsal pathway are not sensitive to color (Gegenfurtner, Kiper, & Levitt, 1997; Maunsell & Van Essen, 1983), suggesting that the unconscious perception in the present study occurred through the ventral pathway. The role of ventral pathway in unconscious visual priming was stressed also by Tapia and Breitmeyer (2011). Of the present experiments, the strongest evidence for unconsciously guided behavior was provided by Experiment 2, which suggest that when Type 1 masked blindsight occurs, the stimulus features (orientation/shape and color) are unconsciously processed separately from each other; they are not bound into the same perceptual object representation. This conclusion follows from the finding that accuracy in discriminating the orientation or color did not depend on accuracy of discriminating the irrelevant feature, that is, discrimination of the orientation did not depend on discrimination of the color, and *vice versa*. This conclusion is similar to that reached by Tapia, Breitmeyer and Shooner (2010) with masked priming. They studied priming of color and form and found that that at the nonconscious level stimuli are processed at an individual feature level, while at the conscious level the stimuli can additionally be processed at a whole-object level.

It has been traditionally assumed that feature binding does not occur outside awareness (Treisman and Gelade, 1980), whereas recent accounts suggest that preconscious binding of features from different domains occurs but it is weak and requires confirmation by attention (Humphreys, 2016), most probably via feedback from posterior parietal areas to early visual cortex (Koivisto & Silvanto, 2012). The present finding in Experiment 2 showing that in Type 1 masked blindsight the discrimination of the features did not depend on each other is consistent with the traditional view, but also with the more recent views stressing the fragile nature of unconscious cross-domain binding. On the other hand, discrimination of the (arrow) shapes requires within-domain binding of the visual elements into the higher-level shape. Type 1 masked blindsight for orientation of shapes did not differ from that for orientation of gratings, which is consistent with the confirmatory binding view (Humphreys, 2016), which assumes that within-domain binding occurs early in processing and without attention.

Each trial in Experiments 1 and 2 required two different responses to the same stimulus. In this sense, the they can be considered as dual-task procedures and thus the results are potentially susceptible to dual-task interference (Pashler, 1994). The two responses might, for instance, interfere with each other, since the response to the second task has to be kept in mind while giving a response to the first task. Furthermore, some time has always elapsed before the second response can be given. At the time of responding to the second task, and with the response given to the first task in between, the representation of the stimulus feature relevant for the second response might be weaker, so that the response in this case might be less accurate. We indeed found that Type 1 masked blindsight to orientation was weaker when the color response preceded the orientation response in Experiment 2, as compared with the condition in which the orientation response was made before the response to the color. However, even when color was responded to before orientation, discrimination of orientation succeeded better than chance level. The 63-67% orientation discrimination accuracy, when the orientation was responded first in Experiment 2, was at the same level as the orientation discrimination accuracy without any awareness (64%) in Experiment 3 in which only one of the features was responded to. This pattern suggests that the dual-task requirement influenced primarily the second response in Experiment 2. It is not possible to decide on basis of the present results whether the longer time elapsed from the target stimulus interfered with the memory representation of the feature needed in responding to the second task, or whether giving the response to the first task as such interfered with the second response. Alternatively, the response order may have influenced the task sets adopted by participants, causing them to attentionally prioritize the feature that had to be responded to first and thus to attend less the feature that had to be responded to after that. Such task set may influence not only memory representations but it may also cause attentional sensitization of unconscious processing (Kiefer & Martens, 2010) of the feature that needs to be reported first.

5.3. Type 2-like masked blindsight

In masked Type 2-like blindsight, the evoked activity is sufficient for the target representation to partially reach the threshold for global availability (Dehaene, 2014) or recurrent processing (Lamme, 2010) to create a sense of awareness of something unidentifiable or irrelevant. In all the present experiments, discrimination without reported awareness of the relevant feature succeeded better than expected by chance, provided that the observers reported having seen at least ‘something’, but not the feature in question. This finding offers evidence for Type 2-like masked blindsight and is consistent with practically all published experiments using graded perceptual scales as a measure of awareness, independent of which type of stimulus or feature must be discriminated (e.g., Song & Yao, 2016; Koivisto et al., 2017; Lähteenmäki et al., 2015; Overgaard et al., 2006; Ramsøy & Overgaard, 2004). It is notable that the feature that is consciously accessed can be totally irrelevant for discriminating the feature that is relevant for performing the task. In Experiment 1, the discrimination of the orientation of Gabors was higher when at least awareness of "something" was reported for its color, a task-irrelevant feature whose relationship to the orientation was arbitrary. However, it is not clear if awareness of any task-irrelevant feature is associated with Type 2-like blindsight. In Experiment 1, reported awareness of color was associated with improved discrimination of orientation, whereas awareness of orientation in discriminating color (without any awareness of color) did not have any relation with performance. How can this asymmetric pattern be explained? First, the color was easier to process than orientation in Experiment 1. This finding is similar to that of Hong and Blake (2009) who found that the color of a bar emerged into consciousness before the orientation of the bar during continuous flash suppression. Similarly, Gelbard-Sagiv et al. (2016) observed that responses to suppressed faces' identity depended on awareness of color of the faces. They suggested that there may be two thresholds: one for consciousness and another one for unconscious processing. According to this view, in the present trials with Type 2-like masked blindsight, the activation of the stimulus representations was higher than in the completely subjectively unaware trials, with the activation of color partly above the threshold for consciousness and, correspondingly, the activation related to orientation below the threshold for consciousness but above the threshold for unconscious processing. As color was closer to the threshold for awareness, the link between awareness of color and accuracy of orientation discrimination may be simply a correlative one, without any causal relation between the phenomena: the higher the activation level of one feature, the higher it is also for the other one. This correlation could be due to either a general activation level in the visual system or the activation level of the object representation, assuming that the features have been bound at least weakly into the same object.

An alternative interpretation for the advantage in processing of color can be developed of the basis of the framework of Breitmeyer (2014) which is inspired by Grossberg’s (2003) work. Perceived color and lightness are examples of surface qualia, whereas perceived form or shape of visual objects (orientation, curvature, size) are geometric qualia as they are characterized by spatial extent. Breitmeyer (2014, p. 65) proposes that “the perception of geometric qualia, that is, conscious registration of a scene’s or object’s form attributes, such as orientation, curvature, or size, depends necessarily on the conscious registration of sensory surface qualia such as color”. In this framework, unconscious processing of geometric features precedes that of surface features, but conscious perception of geometric features requires that the frames created by unconsciously processed geometric features are first filled by surface features. Thus, color precedes orientation in conscious perception, and the advantage in processing of color observed in the present experiments may result from an inherent feature of conscious processing. In this framework, awareness of color might have a causal link to processing of orientation without awareness, provided that its effect occurs very near the threshold of awareness for orientation, just prior filling the frames with surface qualia has been completed and the shape enters awareness.

5.4. Masking

Why did not Type 1 masked blindsight emerge in the condition where only Type 2-like blindsight was observed? Our explicit aim was not to study the effects of spatiotemporal characteristics of mask. We used different masks in the attempt to control for the difference in awareness between color and orientation in Experiment 1. However, comparison of the results of Experiment 1 and Experiment 2 revealed that the type of the mask influenced the results, and Experiment 3 replicated the influence of mask type. Why should characteristics of mask influence the results? It is known that masking is stronger, the more similar the mask is to the target in the spatial frequency spectrum

(Drewes, Zhu, & Melcher, 2018; Ishikawa, Shimegi, & Sato, 2006; White & Lorber, 1976). In Experiment 1, the masks included transparent gratings that had the same spatial frequency as the targets, whereas in Experiment 2 the gratings in the mask had twice as high frequency as the targets, resulting in lesser interference in the channel that processed the orientation of the target. Thus, sensory inputs related to the target could progress with lesser interference in the relevant channel. However, when the mask and target resembled each other more closely, the signal-to-noise ratio decreased to the level that was less able to support unconsciously guided decisions.

Systematic studies on the influence of the similarity of the mask and target on unconscious processing is lacking, and parametrical manipulations of the characteristics of both mask and target are needed. In any case, it is clear that when a mask prevents a stimulus entering awareness, it must necessarily interfere with a mechanisms that works at unconscious level. Therefore it is logical that in the present study the influences of the mask type were observed predominantly in trials without reported awareness of the stimulus.

The present study used backward masking to suppress visual awareness. In backward masking, the stimulus can be processed cortically without any disruption from the mask for a short period of time (i.e., the SOA). This is a clear difference as compared with some other procedures (e.g., continuous flash suppression or sandwich masking) that are often used to suppress awareness in normal observers. Sandwich masking (e.g., Peters & Lau, 2015) combines both forward and backward masking to obtain strong masking effects: the stimulus is presented temporally between two masks, or between 6 masks as was the case in Peters and Lau study. Forward mask is known to have a suppressive effect on vision, although the effect is smaller than that of backward mask (Breitmeyer & Ogmen, 2006). The forward mask interferes with feedforward processing and thus it is not clear whether or not the present results will generalize to masking procedures in which forward mask is applied, or the procedures using several forward and backward masks which can be assumed to suppress perceptual processing more strongly as compared with the single backward mask used in the present study.

The present experiments used three target-mask onset asynchronies (SOAs): 24, 48, and 83 ms. Backward masking can be based on integration masking or interruption masking (Bachmann & Allik, 1976; Turvey, 1973), depending among other things on SOA. Interruption masking occurs when the mask interrupts the processing of target, whereas integration masking occurs at short SOAs when the target and mask integrate into a composite perception. Thus, the mask can inherit some features of the target (Herzog, Otto, & Öğmen, 2012). Feature integration or inheritance, if it occurs in masking studies on unconscious processing, may lead to a content criterion problem. At short SOA, the participant may perceive the inherited feature as a feature of the mask, not of the target, biasing the participant to give the lowest subjective rating of awareness for the target ("nothing seen"). The inherited feature in the mask representation might then bias discrimination responses, if the characteristics of the mask are used as criterion content for responding. The analyses of the present critical results by SOA indicated, however, that the effects supporting the existence of unconsciously guided behavior were observed also at the longest SOA of 83 ms where integration masking should be low or absent and interruption masking should prevail. On average, the estimated accuracy levels tended to be the highest at the longest SOA, although non-significantly. These findings cannot rule out the possibility that integration masking occurred at the short SOA, but in showing that the critical effects did not depend on SOA, they suggest that integration masking/feature inheritance was not necessary for the occurrence of above-chance discrimination without reported awareness.

5.5. The criterion problem

Subjective measures of awareness have been criticized, because observers tend to report awareness with a conservative criterion. In other words, they report unawareness rather than awareness of the stimulus even when they may have had a faint aware perception of it. This is the criterion problem (Eriksen, 1960). Thus, the classification of the trials into “unconscious” and “conscious” ones is not necessarily reliable as the trials rated as “unconscious” actually contain conscious trials and therefore the “unconscious effects” may be driven by aware perception. Experiments 1 and 2 included trials in which the participants reported seeing “nothing” (i.e., no stimulus at all) in response to one of the features, while seeing “something” or even “almost clearly” or “clearly” the other feature in the same trial. This inconsistency obviously reveals that the subjective ratings are not always reliable and that the criterion may fluctuate even within single trials.

In Experiment 2, awareness of the irrelevant feature was not associated with facilitated discrimination of the task-relevant feature in any of the conditions. The response criterion was liberal in Experiment 2: awareness was reported rather than unawareness even when the trials did not involve a stimulus. Thus, a conservative criterion may not explain the observed above-chance accuracy without any reported awareness. Rather, the discrepancy between subjective ratings within some of the trials may be due to liberal criterion: in fact the observers may not have been aware of the presence of the stimulus but sometimes they exaggerated their awareness and gave higher subjective ratings than what they actually experienced in response to one of the features. However, this liberal criterion may also result from illusory perception of seeing the expected target's feature in catch trials, thus creating a false alarm (Aru, Tulver, & Bachmann, 2018). This “reversed criterion problem” would explain why discrimination was not facilitated as a function of (reported) awareness of the irrelevant feature in trials without any reported awareness of the relevant feature – there was no awareness of the irrelevant feature. It is also worth noting that the criterion problem is typically associated to subjective ratings of awareness. In Experiment 2, we observed Type 1 masked blindsight when forced-choice discrimination of the task-irrelevant feature was performed incorrectly, which provides an objective control for awareness, although only in relation to task-irrelevant feature.

Peters and Lau (2015) avoided the criterion problem by using a bias free measure of awareness, a two-interval forced-choice task. The measure of awareness consisted of betting on which of the two possible intervals the discrimination was more confident, while the target was present only in one of the intervals. They found that the thresholds for subjective awareness and objective discrimination of orientation were the same, providing no support for unconscious processing. Their sandwich masking procedure included three forward masks and three backward mask in each interval. It is clear on basis of the present findings that the phenomenon of unconscious visual processing, if it exists, is sensitive to masking conditions. Therefore it would be important to try to replicate the present finding of Type 1 masked blindsight with the two-interval forced-choice task, but using only one backward mask in each interval to avoid unnecessary interfering effects of the additional masks.

5.6. Conclusions

The results suggest that unconsciously guided decisions may be based on two different mechanisms. Either unbound or weakly bound features are processed without any subjective awareness of the task-relevant and irrelevant features (Type 1 masked blindsight). This presupposes that the spatial frequency channel required for processing the shape of the stimulus is free from interference from the mask. Or if that is not the case, completely unconscious stimuli do not have enough strength to guide responding, and at least limited awareness of the stimulus is involved (Type 2-like masked blindsight). It must be kept in mind that the present study followed the typical procedure in blindsight studies by examining whether or not subjectively unaware stimuli can guide behavior: the stimulus must be processed all the way from the earliest visual stages to the decision stage to guide motor output. Therefore, it is likely that here the extent of unconscious processing is underestimated as compared, for example, with unconscious activations observed in functional brain imaging which can show activations of visual cortex and other brain areas in response to different types of unconscious visual stimuli (Brooks et al., 2012), although such activations do not necessarily have enough power to guide behavioral responses. Methodologically, the results show that subjective criteria may fluctuate even within single trials, indicating that subjective reports are not completely reliable indexes of conscious perception.

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