The nature of visual awareness at stimulus energy and feature levels: A backward masking study

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Abstract

The *level of processing* (LoP) hypothesis proposes that low-level stimulus perception (i.e., stimulus energy and features) is a graded process whereas high-level (i.e., letters, words, meaning) stimulus perception is all-or-none. In the present study, we set up a visual masking design in order to examine the nature of visual awareness at stimulus *energy* (i.e., detection task) and *feature levels* (identification task) at specific individual target durations (13, 27, 40, 53, and 80 ms). We manipulated the strength of the masking to produce different visibility conditions and gathered participants' subjective (across a 4-point awareness scale) and objective (accuracy levels) awareness performances. We found that *intermediate ratings* (i.e., ratings 2 and 3, which index graded awareness experiences) were used in more than 50% of the trials for target presentations of 27, 40, 53, and 80 ms. In addition, objective accuracy performances for target presentations of 27 and 80 ms produced linearly increasing detection and identification accuracies across the awareness scale categories, respectively. Overall, our results suggest that visual awareness at *energy* and *feature levels* of stimulus perception may be graded. Furthermore, we found a divergence in detection and identification performance results, which emphasizes the need for an adequate election of target durations when studying different perceptual processes such as detection versus more complex stimulus identification processes. Finally, “clarity” in the perceptual awareness scale should be exhaustively defined depending on the *level of processing* of the stimulus, as participants may recalibrate the meaning of the different awareness categories depending on task demands.

Keywords Awareness · Consciousness · Graded · Dichotomous · Visual masking

Introduction

The fundamental nature of visual awareness has been, and continues to be, a controversial subject of debate within consciousness research (Overgaard, 2017; Windey, Vermeiren, Atas, & Cleeremans, 2014). While some studies suggest that visual awareness emerges in an all-or-none manner (Asplund,

Fougnie, Zughni, Martin, & Marois, 2014; Del Cul, Baillet, & Dehaene, 2007; Sergent & Dehaene, 2004; Sekar, Findley, Poeppel, & Llinás, 2013), others propose that it develops gradually through different states of subjective awareness (Overgaard, Rote, Mouridsen, & Ramsøy, 2006; Pretorius, Tredoux, & Malcolm-Smith, 2016; Ramsøy, & Overgaard, 2004; Seth, Dienes, Cleeremans, Overgaard, & Pessoa, 2008).

It cannot be ruled out, however, that the conflicting evidence on the nature of visual awareness responds to specific experimental decisions, such as the stimulus type, the method of rendering the stimuli invisible, or the characteristics of the subjective awareness scale. On the one hand, a typical experiment in search of the Neural Correlates of Consciousness (NCC, see Koch, Massimini, Boly, & Tononi, 2016, for a review) usually consists of contrasting brain activity related to visual stimuli that are consciously perceived to be brain activity in response to stimuli that do not produce visual consciousness. This manipulation is achieved either by presenting visual stimuli at the perceptual threshold (where 50% of trials produce awareness and the other 50% do not, e.g., Sekar et al., 2013) or performing *post*

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hoc analyses on objective accuracy performances and/or subjective rating distributions in order to divide participants into aware and unaware conditions (Del Cul et al., 2007; Koivisto & Grassini, 2016). Not surprisingly, these studies usually find that visual awareness is all-or-none. On the other hand, the method selected to make the stimuli unaware may also introduce a confounding variable in the results. In this regard, while paradigms such as the attentional blink may produce more dichotomous subjective experiences (Asplund et al., 2014; Sergent & Dehaene, 2004), masking the stimuli usually yields more graded responses (Overgaard et al., 2006). Furthermore, the number of available categories on a subjective scale of awareness may influence participants' responses. Even though all subjective scales tend to indicate the presence of graded awareness states, the resulting proportion of intermediate ratings differs across the scales. In particular, those scales of greater length and unlabeled intermediate ratings produce more dichotomously distributed subjective ratings (Pretorius et al., 2016). Finally, visual awareness may depend on the depth of stimulus processing (or *level of processing*) associated with a specific experimental task (Kouider, De Gardelle, Sackur, & Dupoux, 2010; Windey & Cleeremans, 2015). According to Kouider et al. (2010), perceptual access to stimulus information would be arranged hierarchically, being the *energy level* of representation at the lowest end of the hierarchy (i.e., stimulus spectrum) and evolving through different levels of stimulus representation such as *feature*, *letters*, *words*, and *meaning*. Thus, the perception of “higher-level” stimulus (such as letters, words, or meaningful stimuli) may produce more dichotomously distributed subjective experiences, whereas “lower-level” stimulus characteristics (stimulus at its basic energy or feature levels) would be perceived according to a more graded pattern (see Windey et al., 2014, for a review). In addition, the *levels of processing* hypothesis suggests that the transition from *energy* to *feature level* should be conceived as gradual, whereas the transitions at the higher levels of processing should be considered as dichotomous (Windey & Cleeremans, 2015). According to this view, low- and high-level stimuli would differ on how they emerge to consciousness (more gradually vs. more dichotomously) because of their different nature and how they are labelled. While high-level stimuli (such as letters, numbers, and words) do typically refer to a precise concept, low-level stimuli (at an energy or feature level) cannot easily be associated with a single label.

Whereas previous evidence seems to be in agreement with this account (Anzulewicz, Asanowicz, Windey, Paulewicz, Wierzchoń, & Cleeremans, 2015; Binder et al., 2017; Windey, Gevers, & Cleeremans, 2013), a recent study by Kiefer and Kammer (2017) cast some doubts on the graded versus dichotomous nature of visual awareness at different depths of stimulus processing. These authors explored how context characteristics, such as task or stimulus feature (stimulus absent/present, capital, lexical or semantic) or the masking method (random pattern mask, false font mask, random letter mask, and word mask),

modulated the gradual versus dichotomous emergence of visual awareness. Data for different stimulus-onset asynchronies (SOAs) were fitted into a psychometric function, where threshold and slope analysis were conducted (see Del Cul et al., 2007, and Koch & Preusschoff, 2007, for similar analyses). The absence/presence of the task showed the lowest awareness threshold, which suggests that stimulus presence (“energy”) is rapidly consciously accessible. In contrast, higher awareness thresholds were related to complex letter, lexical, or semantic features. Noteworthy, when the slopes of the fitted psychophysical functions within each task were analyzed, the steepest slope (thus the less graded) was found for the absence/presence task (i.e., lowest level stimulus processing). This effect was not modulated by masking, which suggests a rather discontinuous emergence of basic visual awareness. Slopes for the higher-level letter, lexical and semantic discrimination tasks were shallower (thus more graded) and did not differ from each other.

Interestingly, while research on the *levels of processing* framework usually consists of presenting a wide range of target durations (Anzulewicz et al., 2015; Binder et al., 2017; Windey et al., 2013) or target-mask SOAs (Kiefer & Kammer, 2017) to explore the *emergence* of visual awareness for increasing stimulus intensities, no previous study has systematically addressed the nature of visual awareness at specific, fixed, target durations/SOAs. Furthermore, the relation between objective accuracy levels and subjective awareness reports (i.e., accuracy performances at each awareness category) at selected target durations has not yet been thoroughly investigated within the *levels of processing* framework. In addition, an in depth exploration of awareness patterns at stimulus *feature level*, which is situated at the intersection between the lowest (i.e., energy) and higher (letter, words, meaning) processing levels (Windey & Cleeremans, 2015), seems to be lacking within the *levels of processing* framework.

In sum, the reviewed evidence suggests that there are still some crucial questions to be answered within research on the nature of visual awareness from a *levels of processing* perspective. Specifically, what is the nature of the elementary visual experience at its most basic *energy level*? Does visual awareness at the stimulus *feature level* follow a graded or an all-or-none pattern?

In order to explore these open issues, we set up an experimental design that allowed us to examine the nature of visual awareness at the *low end* of the stimulus-processing hierarchy (i.e., *energy* and *feature levels*; Kouider et al., 2010). To achieve this, (1) we had to use an experimental design potentially able to restrict visual awareness in a graded manner; (2) we had to use visual stimuli at the *low-level end* of the stimulus-processing spectrum, and (3) we had to make use of an appropriate subjective awareness scale in order to accurately collect possible intermediate states of subjective awareness. Accordingly, we decided to set up our experiments using (1) a visual masking paradigm, (2) “low-level” visual stimuli based on luminance contrast

(*energy*) and shape features (*feature level*), and (3) a 4-point subjective awareness scale adapted from the PAS scale (Ramsøy & Overgaard, 2004), with the ratings 1 – *no perception*, 2 – *weak perception*, 3 – *almost clear perception*, and 4 – *clear perception*. Moreover, with the intention of assessing the emergence of visual awareness both at the stimulus *energy* and *feature levels*, we used two different experimental tasks: a detection task for the elementary visual experience, and an identification task for the stimulus *feature level*. Crucially, here we intended to explore the graded or dichotomic nature of visual awareness at specific target durations (i.e., at fixed-stimulus presentations). This would allow us to explore temporal differences in the emergence of awareness at stimulus *energy* (i.e., detection) and *feature* (i.e., identification) levels of representation. With this intention, we manipulated the strength of the masking by varying its degree of organization, as prior evidence has shown a link between masking strength and the global regularity of the mask (Ghose, Hermens, & Herzog, 2012; Hermens, & Herzog, 2007). Specifically, regular patterns seem to be less effective for masking stimuli when compared to random patterns (Coltheart, & Arthur, 1972). Therefore, we used a novel masking design that manipulated the regularity of the mask by means of brightness differences in local dot elements (based on similar stimuli used by Kurylo & Bukhari, 2015) in order to produce different degrees of awareness at each independent stimulus duration.

Based on the results of preliminary pilot tests, we decided to explore three different stimulus durations for stimulus-detection task (Study 1 – Experiment 1: 13 ms, Experiment 2: 27 ms, and Experiment 3: 40 ms) and three different stimulus durations when targets had to be also discriminated (Study 2 – Experiment 4: 27 ms, Experiment 5: 53 ms, and Experiment 6: 80 ms). In order to explore the nature of visual awareness at these different individual target durations, both subjective (i.e., awareness report distribution) and objective (accuracy performances) measures were analyzed. If stimulus processing at *energy* and *feature* levels of representation followed a graded pattern of visual awareness, we would expect participants to report a significant number of intermediate awareness ratings¹ across the studied target durations. Conversely, if visual awareness at stimulus *energy* and *feature* levels followed an all-or-none pattern, intermediate ratings would be marginally used across all target durations. Interestingly, if visual awareness is graded at stimulus *energy level* but dichotomous at stimulus *feature level*, intermediate reports would be significantly used in Study 1 yet marginally used in Study 2. Importantly, accuracy performances would provide an objective measure of awareness for each task. A

significant relationship between accuracy and awareness ratings would suggest that the different awareness ratings are sensitive to participants' awareness levels (note that the PAS scale is able to show strong performance-awareness correlation; Sandberg, Timmermans, Overgaard, & Cleeremans, 2010). In addition, trend analyses on accuracy levels across awareness categories would provide meaningful data on the linear versus non-linear nature of the objective awareness measure at the different specific target durations: a significant *linear trend* shows that accuracy performances increase proportionately across the awareness categories, thus suggesting a graded pattern of awareness, whereas a *quadratic trend* signals a curve in the pattern, and therefore a non-linear increase in objective accuracy levels (Maxwell & Delaney, 2003). The use of trend analysis has been previously implemented for testing linear relations between PAS categories and accuracy levels (Tagliabue, Mazzi, Bagattini, & Savazzi, 2016), and in the exploration of levels of processing hypotheses at individual target durations (see Jimenez, Grassini, Montoro, Luna & Koivisto, 2018, for a similar analysis).

Study 1: Stimulus energy level

In order to explore the nature of visual awareness at the stimulus *energy level*, three different experiments (13, 27, and 40 ms stimulus durations) were conducted where participants performed a target-detection task.

Experiment 1: Target presentation of 13 ms

Method

Participants Twenty-four students (19 women, age range = 18–50 years, $M = 32$; $SD = 11.3$) from the Universidad Nacional de Educacion a Distancia (UNED) took part in the study. All of them had normal or corrected-to-normal vision and received course credits for their participation.

Stimuli and apparatus The stimuli were displayed on a 19-in. LCD–LED Samsung 943N color monitor with a 75-Hz refresh rate, a 5:4 aspect ratio, and a resolution of 1 280 × 1,024 controlled by a computer running E-Prime 1.2 software (Psychology Software Tools, 1996–2002). Viewing distance was approximately 57 cm. All the stimuli were displayed in the center of the screen subtending a visual angle of $14^\circ \times 14^\circ$. The luminance of the background was 8.3 cd/m^2 .²

The target consisted of a square form of clear dots (33.2 cd/m^2) that could be detected against the darker dots (0.07 cd/m^2)

¹ Since a perfectly graded awareness distribution would produce equal awareness reports for the four awareness levels (i.e., 25% of reports at each level), we set that percentage as a measure of a significant number of reports when exploring the use of intermediate ratings (i.e., rating 2 and rating 3). The more frequent use of middle ratings is assumed to reflect more graded visibility (Anzulewicz et al., 2015; Sandberg, Timmermans, Overgaard, & Cleeremans, 2010; Windey et al., 2014).

² The timing of events was measured using an external device CEV1 (made by CIBERTEC S.A.), which verifies the timing with a precision of milliseconds by means of a photodiode BPN 77NA connected to an internal chronometer.

of the background (*light square*, see Fig. 1a), and was presented on a grid of 20×20 local elements (dots), each dot subtending a visual angle of 0.4° . The *light squares* were composed of 12 clear dots, their sides subtending a 2.4° visual angle. Targets appeared in one of the four quadrants of the grid. The center of the target in each quadrant was at 4.7° from the center of the screen. In the center of the three quadrants where the target did not appear, a clear (33.2 cd/m^2) dot appeared at 4.7° from the center of the screen. The remaining local elements of the grid were dark dots.

The masks were composed of a grid of 20×20 local elements (dots), half of them clear (33.2 cd/m^2) and the other half of them dark (0.07 cd/m^2). There were six different mask types based on their degree of organization (100% organization, 90%, 80%, 70%, 60%, and 50%) (see Fig. 1c). More irregular masks were generated by introducing opposite luminance dots into each column/row: 90% organization masks had 90% same brightness dots in each column/row, 80% organization masks had 80% same brightness dots in each column/row, etc. Eventually, in the 50% organization mask, the different brightness dots were randomly distributed across the mask. Each mask was created by gluing together four sub-masks randomly assigned to each quadrant of the stimulus (see Fig. 1d). There were four different sub-masks to be assigned for each mask organization, two in the vertical axis and two in the horizontal axis. This manipulation was intended to create effective and homogenous masking conditions across all four grid quadrants. At the same time, it would allow us to create masks with different masking strengths while, importantly, keeping the duration and energy of the stimuli constant. There were 24 mask variations for each organization (90% to 50%) and two possible masks for the most organized mask type (100%), for a total of 122 possible masks.

Procedure and design The task consisted of detecting in which of the four quadrants the *light square* target appeared. It was completed individually in dimly lit experimental cabins. Before the task, the targets were shown on a projector screen and participants were informed about the sequence of events. Specifically, participants were informed that in each trial the *light square* would be briefly flashed and backward masked, whereas their task would be to inform in which of the four quadrants it appeared. Participants were informed that, if they did not see or were not sure on which quadrant the target appeared, they had to guess the response by clicking randomly on one of the four quadrants. The sequence of events for the detection task in Study 1 is shown in Fig. 2a. In each trial, an initial (“ready?”) screen appeared until participants pressed the space bar on their keyboards. When pressed, it activated a “3-2-1 countdown,” after which the target appeared for 13 ms, followed by the mask for a duration of 27 ms. Immediately after, the first response screen was shown in

which participants indicated the target location by clicking with the mouse on one of the four possible quadrants that were displayed. This was followed by the second response screen, where participants indicated their subjective awareness by clicking with the mouse on one of the four possible ratings. The response options appeared in four horizontally-oriented rectangles, which ranged from (1) *no perception* to (4) *clear perception*, with the intermediate options (2) *weak perception* and (3) *almost clear perception*. A blank, inter-trial screen then appeared for 800 ms. The experimental session started with a practice block of 24 trials followed by five blocks of 48 trials each, yielding a total of 240 experimental trials. In order to avoid fatigue effects, participants were allowed to rest at their convenience between experimental blocks.

Results and discussion

Subjective awareness Participants predominantly used *no perception* (rating 1) in 73% of the trials, with *weak perception* being the second most used category (rating 2: 22.5% of the trials) (see Table 1 and Fig. 3a³). Intermediate ratings (i.e., aggregated ratings 2 and 3) were reported in only 27 % of the trials (see Fig. 3a and b). Overall, these results suggest that participants’ subjective awareness of the stimulus was very low when the target was presented for 13 ms.

In order to explore possible awareness rating differences at different mask organizations, we conducted a 6 (Mask Organization: 100%, 90%, 80%, 70%, 60%, 50%) $\times$ 4 (Awareness: 1, 2, 3, 4) repeated-measures ANOVA on the mean use of awareness reports. Results showed that Mask Organization did not interact with Awareness ($F(15,345) = 0.87$, $MSE = 4.26$, $p = .599$, $\eta_p^2 = .03$), indicating that the different mask organizations did not produce different awareness distributions.

Detection results

Detection accuracy was significantly above chance level (.25) when participants reported *no perception* (rating 1: .33; $t(23) = 3.93$; $p < .001$), whereas accuracies for the remaining awareness levels were as follows: rating 2 = .47, rating 3 = .55, and rating 4 = .62 (see Table 1 and Fig. 3c).

Detection accuracies were analyzed in SPSS (SPSS 20, IBM corp. Released 2011) using a linear mixed-effects model (McCulloch & Searle, 2004) in order to avoid the listwise deletion of missing values (missing accuracies for unreported awareness levels). Following maximum likelihood estimation (MLE), Mask Organization and Awareness were introduced as fixed effects to the model and Subjects as random variable. Results showed no significant effect for Mask Organization ($F(5,322) = 324.31$, $p = .581$), indicating that different mask

³ Accuracy distributions were transformed to % of trials (see Figs. 3 and 4) in order to facilitate data interpretation.

Fig. 1 (a) Targets in Study 1, (b) Targets in Study 2, (c) Mask organizations, and (d) Mask composition

types did not produce different accuracy levels. A significant effect for Awareness ($F(3,322) = 5.09$, $p = .002$) suggested that different awareness categories produced different accuracy levels, whereas Mask Organization did not interact with

Awareness ($F(15,322) = 0.93$, $p = .527$). Individual mean accuracies at each awareness rating were subjected to a one-way ANOVA in order to conduct trend analyses for Awareness. A significant linear trend ($F(3,56) = 7.58$, MSE

Fig. 2 (a) Sequence of events in Study 1. (b) Sequence of events in Study 2

Table 1 Results of Study 1: Awareness ratings (in %) and accuracy performances (percentage correct) at each awareness rating

Study 1	Awareness scale			
	1-no perception	2-weak perception	3-almost clear	4-clear perception
Awareness Reports				
Exp. 1 – 13 ms	73%	22.5%	4%	0.5%
Exp. 2 – 27 ms	34%	44%	18%	4%
Exp. 3 – 40 ms	11%	25%	34%	30%
Detection Accuracy				
Exp. 1 – 13 ms	.33	.47	.55	.62
Exp. 2 – 27 ms	.34	.52	.73	.81
Exp. 3 – 40 ms	.47	.83	.93	1.00

= 0.07, $p = .008$, $\eta^2_p = .12$) indicated that accuracy levels increased linearly across the awareness scale. Nonetheless, objective performances did not reach high accuracies across the awareness scale (i.e., 62% at clear perception; see Table 1 and Fig. 3c), which in line with the subjective awareness

distribution, suggests that a target presentation of 13 ms was a very restrictive condition in order to produce either a gradual or a dichotomic pattern of awareness experiences.

Experiment 2: Target presentation of 27 ms

Method

Participants Twenty-three students (20 women, age range = 20–62 years, $M = 34$; $SD = 13.6$) from the UNED took part in the study. All of them had normal or corrected-to-normal vision and received course credits for their participation.

Stimuli and apparatus Stimuli and apparatus were identical to those used in Experiment 1.

Procedure and design The procedure and design were identical to Experiment 1, with the exception that the target was presented for 27 ms.

Fig. 3 Results of Study 1: (a) awareness ratings (in %) at the different stimulus durations, (b) intermediate ratings (in %) at the different stimulus durations, (c) accuracy performances (proportion correct) per awareness rating. Error bars represent standard deviations (SDs)

Results and discussion

Subjective awareness *No perception* reports (rating 1) were used in 34% of the trials, with *clear perceptions* (rating 4) being reported in only 4% of the trials (see Table 1 and Fig. 3a). Interestingly, *weak perception* (rating 2) was significantly used in 44% of trials, whereas *almost clear perceptions* were also frequently used (rating 3: 18% of trials). Overall, a target presentation of 27 ms produced a high number of intermediate ratings, ratings 2 and 3 together being reported in 62% of the trials (see Fig. 3a and b).

Again, a 6 (Mask Organization: 100%, 90%, 80%, 70%, 60%, 50%) $\times$ 4 (Awareness: 1, 2, 3, 4) repeated-measures ANOVA on the mean use of awareness reports was conducted. Results showed no interaction between Mask Organization and Awareness ($F(6,134) = 2.02$, $MSE = 9.94$, $p = .065$, $\eta_p^2 = .08^4$), suggesting that different mask organizations did not produce different awareness distributions.

Detection results Detection accuracy was significantly above chance level (.25) when participants reported *no perception* (rating 1: .34; $t(21) = 2.27$; $p = .034$), whereas accuracies for the remaining awareness levels were as follows: rating 2 = .52, rating 3 = .73, and rating 4 = .81 (see Table 1 and Fig. 3c).

Detection accuracies were analyzed using a linear mixed-effects model in order to avoid listwise deletion of missing values. Again, Mask Organization and Awareness were introduced as fixed effects and Subjects as random variable. Results showed no significant effect for Mask Organization ($F(5,355) = 0.22$, $p = .953$), indicating that different mask types did not produce different accuracy levels. A significant effect for Awareness ($F(3,355) = 39.86$, $p < .001$) suggested that different awareness categories produced different accuracy levels, whereas Mask Organization did not interact with Awareness ($F(15,355) = 0.36$, $p = .988$). Individual mean accuracies at each awareness rating were subjected to a one-way ANOVA in order to conduct trend analyses for Awareness, which showed that accuracy levels increased proportionately across the awareness scale, as suggested by a highly significant linear trend for Awareness ($F(3,60) = 24.79$, $MSE = 0.70$, $p < .001$, $\eta_p^2 = .29$). These results are in line with a gradual increase in objective accuracy levels across the awareness scale.

In sum, accuracy performances increased proportionately as a function of awareness of the target and, in addition, both *weak* or *almost clear perception* ratings were reported in more than half of the trials. In combination, both objective and subjective measures of awareness suggest that stimulus processing at energy level may follow a graded pattern for a target presentation of 27 ms.

⁴ Greenhouse-Geisser corrections were applied on p -values and degrees of freedom when the sphericity assumption was violated.

Experiment 3: Target presentation of 40 ms

Method

Participants Twenty-one students (17 women, age range = 19–53 years, $M = 33$; $SD = 12.3$) from the UNED took part in the study. All of them had normal or corrected-to-normal vision and received course credits for their participation.

Stimuli and apparatus Stimuli and apparatus were identical to those used Experiments 1 and 2.

Procedure and design The procedure and design were identical to Experiments 1 and 2, with the exception of a 40-ms target presentation.

Results and discussion

Subjective awareness A target presentation of 40 ms produced a significant use of both *weak* (rating 2: 25% of the trials) and *almost clear* (rating 3: 34% of the trials) perceptions. Intermediate ratings (aggregated ratings 2 and 3) were overall reported in 59% of the trials (see Table 1 and Fig. 3a and b). In addition, *clear perceptions* (rating 4) were also significantly reported in 30% of the trials, whereas *no perception* (rating 1) was reported in only 11% of the trials. Overall, a target presentation of 40 ms produced a less restrictive awareness of the stimulus, both intermediate ratings 2 and 3 being very frequently used.

A repeated-measures ANOVA on the mean use of awareness reports at different mask organizations was again conducted. Results showed that Mask Organization did not interact with Awareness ($F(6,123) = 1.51$, $MSE = 6.75$, $p = .180$, $\eta_p^2 = .07$), suggesting that the different mask organizations did not produce different awareness distributions.

Detection results Detection accuracy was significantly above chance level (.25) when participants reported *no perception* (rating 1: .47; $t(18) = 3.13$; $p = .006$), whereas accuracies for the remaining awareness levels were as follows: rating 2 = .83, rating 3 = .93, and rating 4 = 1.00 (see Table 1 and Fig. 3c).

Detection accuracies were analyzed using a linear mixed-effects model. Mask Organization and Awareness were introduced as fixed effects to the model and Subjects as random variable. Results showed no significant effect for Mask Organization ($F(5,390) = 0.39$, $p = .857$), indicating that different mask types did not produce different accuracy levels. A significant effect for Awareness ($F(3,390) = 117.58$, $p < .001$) suggested that different awareness categories produced different accuracy levels, whereas Mask Organization did not interact with Awareness ($F(15,390) = 0.47$, $p = .955$). Polynomial contrasts produced both significant linear ($F(3,70) = 57.19$, $MSE = 0.04$, $p < .001$, $\eta_p^2 = .48$) and quadratic ($F(3,70) =$

8.97, $MSE = .04$, $p = .004$, $\eta^2_p = .48$) trends for Awareness. A visual inspection of detection performances across the awareness scales (Fig. 3c) showed an abrupt increase in accuracy levels from awareness rating 1 to awareness rating 2, thus following a non-gradual pattern.

Overall, a target presentation of 40 ms was able to produce a significant number of both *weak* (rating 2) and *almost clear* (rating 3) intermediate reports. On the other hand, accuracy performances abruptly increased from rating 1 to rating 2, which suggest that objective detection performance (but not subjective awareness) is very sensitive to small changes in target presentations at stimulus *energy level*.

Study 1: Interim discussion

Results for Experiment 1 showed that a target presentation of 13 ms resulted in a very restrictive visual condition, *no perception* reports (rating 1) being received in 73% of the trials. A target presentation of 27 ms (Exp. 2) produced a predominant number of *weak perceptions* (rating 2: 44 % of trials), with *almost clear perceptions* (rating 3) also being frequently used (18% of trials; aggregated intermediate ratings being informed in 62% of the trials). Finally, awareness ratings were more evenly used when the target was presented for 40 ms (Exp. 3), both *weak* (rating 2) and *almost clear* (rating 3) perceptions being significantly used in 25% and 34% of the trials, respectively (aggregated intermediate ratings being used in 59% of the trials).

Objective accuracy analyses showed that different accuracy levels increased as a function of awareness in all three experiments. When the target was presented for 13 ms (Experiment 1), a small (yet linear) increase in accuracies was observed across awareness ratings (see Table 1 and Fig. 3c). When the target was presented for 27 ms (Exp. 2), accuracy levels proportionately increased at each awareness category, thus following a linear pattern. Finally, when the target was presented for 40 ms (Exp. 3), accuracy levels increased non-linearly across awareness categories.

In sum, both subjective awareness distribution and objective accuracy performances suggest that the stimulus processing at *energy level* may follow a graded pattern when the target is presented for 27 ms. Results from Experiment 3 provide additional evidence that stimulus perception at its most basic *energy level* may produce a significant number of intermediate (both *weak* and *almost clear*) perceptions. In addition, accuracy results at this target presentation suggest that objective accuracy performances are very sensitive to small changes in target presentations at stimulus *energy level*.

Also, different mask organizations did not produce either different awareness distributions or different accuracy levels across the three different target durations. Yet, even though each mask organization was not associated with specific awareness levels, the masking design was successful in

producing different awareness levels (as shown by both subjective and objective awareness measures).

Finally, accuracy levels at rating 1 (*no perception*) were above chance level at the three studied target presentations. These results are consistent with previous evidence (Overgaard et al., 2006; Sandberg et al., 2010) showing that even the detection of very briefly presented masked targets may produce above chance level results. Two different scenarios may explain these results. One possibility is that participants chose the *no perception* rating when they actually had some (*weak*) perception of the target. Alternatively, unconscious processing of the stimulus might have influenced the detection accuracies in the absence of awareness.

Study 2: Stimulus feature level

In order to explore the nature of visual awareness at the stimulus *feature level*, *I-shaped* and *H-shaped* figures (see Fig. 1b) were presented in three different experiments (27, 53, and 80 ms target presentations). Here participants had to both detect and identify the target displayed at one of four possible locations on the screen. The same group of participants from Study 1 took part in the three experiments in Study 2.

Experiment 4: Target presentation of 27 ms

Method

Participants Twenty-three students (20 women, age range = 20–62 years, $M = 34$; $SD = 13.6$) from the Universidad Nacional de Educacion a Distancia (UNED) took part in the experiment. All of them had normal or corrected-to-normal vision and received course credits for their participation. These participants had previously participated in Experiment 2 (same target duration of 27 ms) in Study 1.

Stimuli and apparatus The stimuli and apparatus were identical to those used in Study 1, except for the following: targets consisted of *I-shaped* or *H-shaped* forms generated from the same number of clear dots that made up the *light square* (see Fig. 1b). Therefore, the identification of these two targets would be based on the different geometrical features of each stimulus. *I-shaped* and *H-shaped* targets were composed of 12 clear dots (33.2 cd/m^2) subtended 2.4° at their widest part and 1° at the narrowest (see Fig. 1b).

Procedure and design The experiment consisted of two successive tasks: detecting in which of the four quadrants the *I-shaped* and *H-shaped* targets appeared (detection task) and indicating which of the two shapes had appeared (identification task). Participants completed the tasks individually, in dimly lit experimental cabins. Prior to the

start of the experiment, the targets were shown on a projector screen and participants were informed about the sequence of events. The sequence of events for a trial in Study 2 is shown in Fig. 2b. In each trial, the initial (“Ready?”) screen appeared until participants pressed the space bar, which prompted the “3-2-1 countdown,” and immediately after the target appeared for 27 ms followed by the mask for 27 ms. After that, the first response screen appeared in which participants indicated the target location by clicking with the mouse on one of the four possible quadrants. This was followed by the second response screen where participants indicated their subjective awareness by clicking with the mouse on one of the four possible ratings. Finally, a third response screen appeared, where participants had to report which of the two targets they considered had been shown in each trial (see Fig. 2b) by clicking on one of the two provided options: *I-shaped* or *H-shaped* form. Participants were informed that, if they could not locate or identify the targets, they had to guess the response by clicking randomly. The experiment consisted of a practice block with 24 trials followed by two blocks of 96 trials each, for a total of 192 experimental trials per target duration. In order to avoid fatigue effects, participants were allowed to rest between experimental blocks.

Results and discussion

Subjective awareness Participants’ subjective awareness of the stimulus was very restricted when the *I-shaped* and *H-shaped* stimuli were presented for 27 ms, as shown by *no perception* (rating 1) being reported in more than half of the trials (51%) and *clear perception* (rating 4) being marginally used in 2% of the trials (see Table 2 and Fig. 4a). *Weak perception* (rating 2) was significantly used in 39% of the trials, but *almost clear perceptions* (rating 3) were reported in only 8% of the trials, the total number of intermediate ratings not reaching half of the reports (47%) (see Fig. 4a and b).

In order to explore possible awareness rating differences at different mask organizations, a 6 (Mask Organization: 100%, 90%, 80%, 70%, 60%, 50%) $\times$ 4 (Awareness: 1, 2, 3, 4) repeated-measures ANOVA on the mean use of awareness reports was conducted. Results showed no interaction between Mask Organization and Awareness ($F(5,99) = 2.27$, $MSE = 15.80$, $p = .059$, $\eta_p^2 = .09$), suggesting that different mask organizations did not produce different awareness distributions.

Detection results Detection accuracy was significantly above chance level (.25) when participants reported *no perception* (rating 1: .37; $t(22) = 2.49$; $p = .021$), whereas accuracies for the remaining awareness levels were as follows: rating 2 = .43, rating 3 = .48, and rating 4 = .43 (see Table 2 and Fig. 4c).

Table 2 Results in Study 2: Awareness ratings (in %) and accuracy performances (proportion correct) at each awareness rating

Study 2	Awareness scale			
	1 – no perception	2 – weak perception	3 – almost clear	4 – clear perception
Awareness Reports				
Exp. 4 – 27 ms	51%	39%	8%	2%
Exp. 5 – 53 ms	16%	48%	26%	10%
Exp. 6 – 80 ms	3%	21%	30%	46%
Detection Accuracy				
Exp. 4 – 27 ms	.37	.43	.48	.43
Exp. 5 – 53 ms	.60	.91	.99	.97
Exp. 6 – 80 ms	.54	.96	.98	.97
Identification Acc.				
Exp. 4 – 27 ms	.51	.50	.35	.66
Exp. 5 – 53 ms	.57	.55	.68	.63
Exp. 6 – 80 ms	.67	.76	.91	.91

Detection accuracies were analyzed using a linear mixed-effects model (McCulloch & Searle, 2004) in order to avoid listwise deletion of missing values (missing accuracies for unreported awareness levels). Following maximum likelihood estimation (MLE), Mask Organization and Awareness were introduced as fixed effects to the model and Subjects as random variable. Results showed no significant effect for Mask Organization ($F(5,339) = 0.40$, $p = .843$), indicating that different mask types did not produce different accuracy levels. A significant effect for Awareness ($F(3,339) = 8.22$, $p < .001$) suggested that different awareness categories produced different accuracy levels, whereas Mask Organization did not interact with Awareness ($F(15,339) = 1.00$, $p = .450$). Individual mean accuracies at each awareness rating were subjected to a one-way ANOVA in order to conduct trend analyses for Awareness, which did not show any significant trend. In sum, objective accuracy analyses were low through all awareness categories, which suggests that *I-shaped* and *H-shaped* targets presented for a SOA of 27 ms were very difficult to detect.

Identification results Identification accuracy was at chance level (.50) when participants reported *no perception* of the stimulus (rating 1: .51; $t(22) = .35$; $p = .731$), whereas accuracies for the remaining awareness levels were as follows: rating 2 = .50, rating 3 = .35, and rating 4 = .66 (see Table 2 and Fig. 4c).

Identification accuracies were analyzed using a linear mixed-effects model. Mask Organization and Awareness were introduced as fixed effects to the model and Subjects as random variable. Results showed no significant effect for Mask Organization ($F(5,339) = 1.37$, $p = .232$), indicating that

Fig. 4 Results of Study 2: (a) Awareness ratings (in %) at the different stimulus durations, (b) intermediate ratings (in %) at the different stimulus durations, (c) accuracy performances (proportion correct) per awareness rating. Error bars represent standard deviations (SDs)

different mask types did not produce different accuracy levels. A significant effect for Awareness ($F(3,339) = 4.14, p = .007$) suggested that different awareness categories produced different accuracy levels. In addition, Mask Organization interacted with Awareness ($F(15,339) = 1.99, p = .015$). The exploration of pairwise comparisons (Bonferroni corrected) showed that the only significant differences in accuracy levels were observed at rating 3 (*almost clear perception*) between 60%

and 90% ($p = .025$), 70% and 90% ($p = .005$) and 90% and 100% mask organizations ($p = .004$), accuracy levels being lower for 90% mask organization in all cases. All other pairwise comparisons produced an absence of accuracy differences per awareness category across mask organizations (all $ps > .05$). Individual mean accuracies at each awareness rating were subjected to a one-way ANOVA in order to conduct trend analyses for Awareness, results showing a significant

quadratic trend ($F(3,69) = 7.57$, $MSE = 0.04$, $p = .008$, $\eta^2_p = .18$). A visual inspection of feature identification results (Fig. 4) showed that all awareness categories were linked to low accuracy levels, whereas the quadratic trend reflected an initial drop in accuracies from rating 2 to rating 3, and the following increase in accuracy level at rating 4. Thus, even though accuracies were low for both stimulus detection and identification at all awareness levels, *almost clear* and *clear* ratings were still (marginally) reported, which suggest that some participants may show a tendency to use all available awareness categories even when stimulus visibility is very restrictive.

Interestingly, although accuracy levels were above chance level for the detection of the stimulus when observers reported *no perception* of the stimulus (rating 1), they were at chance level for the identification of target features.

Overall, both subjective and objective awareness measures suggest that a SOA of 27 ms was a very short target presentation in order to produce either a gradual or a dichotomic pattern of awareness experiences at either stimulus *energy* or *feature levels*.

Experiment 5: Target presentation of 53 ms

Method

Participants Twenty-four students (19 women, age range = 18–50 years, $M = 32$; $SD = 11.3$) from the UNED took part in the experiment. All of them had normal or corrected-to-normal vision and received course credits for their participation. These participants had previously participated in Experiment 1 (target presentation of 13 ms) in Study 1.

Stimuli and apparatus Stimuli and apparatus were identical to those used Experiment 1.

Procedure and design The procedure and design were identical to Experiment 4, with the exception that the target was presented for 53 ms.

Results and discussion

Subjective awareness When targets were presented for 53 ms, a significant number of *weak* (rating 2: 48% of the trials) and *almost clear* (rating 3: 26% of the trials) perceptions were reported (see Table 2 and Fig. 4a and b). Intermediate ratings were thus reported in 74% of the trials. The extremes of the scale, on the other hand, were only reported in 26% of the trials (rating 1: 16%, rating 4: 10%).

A repeated-measures ANOVA on the mean use of awareness reports at different mask organizations was conducted, which showed a significant interaction between Mask Organization and Awareness ($F(7,164) =$

2.63, $MSE = 8.77$, $p = .013$, $\eta^2_p = .10$), suggesting that different mask organizations did produce different awareness reports. Pairwise comparisons (Bonferroni corrected), however, showed that different awareness reports were used equally across different mask organizations (all $ps > .05$)

Detection results Detection accuracy was significantly above chance level (.25) when participants reported *no perception* (rating 1: .60; $t(20) = 6.70$; $p < .001$), whereas accuracies for the remaining awareness levels were as follows: rating 2 = .91, rating 3 = .99 and rating 4 = .97 (see Table 2 and Fig. 4c).

Detection accuracies were again analyzed using a linear mixed-effects model. Mask Organization and Awareness were introduced as fixed effects to the model and Subjects as random variable. Results showed no significant effect for Mask Organization ($F(5,417) = 1.52$, $p = .183$), indicating that different mask types did not produce different accuracy levels. A significant effect for Awareness ($F(3,417) = 86.19$, $p < .001$) suggested that different awareness categories produced different accuracy levels, whereas Mask Organization did not interact with Awareness ($F(15,417) = 1.14$, $p = .316$). Individual mean accuracies at each awareness rating were subjected to a one-way ANOVA in order to conduct trend analyses for Awareness, which produced both a linear ($F(3,79) = 67.38$, $MSE = 0.02$, $p < .001$, $\eta^2_p = .54$) and a quadratic ($F(3,79) = 25.32$, $MSE = 0.02$, $p < .001$, $\eta^2_p = .54$) trend. A visual inspection of detection performances across the awareness scales (Fig. 4c) showed an abrupt increase in accuracy levels from awareness rating 1 to awareness rating 2, thus following a non-gradual pattern.

Identification task Identification accuracy was at chance level (.50) when participants reported *no perception* (rating 1: .57; $t(20) = 1.48$; $p = .153$), whereas accuracies for the remaining awareness levels were as follows: rating 2 = .55, rating 3 = .68 and rating 4 = .63 (see Table 2 and Fig. 4c).

Identification accuracies were analyzed using a linear mixed-effects model, Mask Organization and Awareness being introduced as fixed effects to the model and Subjects as random variable. Results showed no significant effect for Mask Organization ($F(5,417) = 2.10$, $p = .064$), indicating that different mask types did not produce different accuracy levels. A significant effect for Awareness ($F(3,417) = 9.33$, $p < .001$) suggested that different awareness categories produced different accuracy levels, whereas Mask Organization did not interact with Awareness ($F(15,417) = 0.83$, $p = .645$). Individual mean accuracies at each awareness rating were subjected to a one-way ANOVA in order to conduct trend analyses for Awareness, which did not produce any significant effect.

Therefore, a stimulus presentation of 53 ms produced a divergence in objective performances between the stimulus processing at *energy* versus *feature levels*. Whereas this target

duration produced an abrupt increase in accuracy performances at stimulus *energy level* (i.e., detection task) from rating 1 (*no perception*) to the other awareness categories, feature identification performances were very low across all awareness categories. Thus, at this stimulus duration a particular scenario seems to emerge: Detection accuracies showed that target localization was accomplished easily, whereas feature identification remained very challenging. Accordingly, it may be possible that at this target duration, reported subjective awareness were influenced to some extent by subjective perceptions associated with the lower-level (detection) task.

In line with the results from Experiment 4, accuracy was above chance level for stimulus detection when observers reported *no perception* of the stimulus (rating 1), but they were at chance level for the identification of target features. These results suggest that stimulus detection but not identification is influenced by unconscious processing of the target at target presentations of 53 ms and below.

Experiment 6: Target presentation of 80 ms

Method

Participants Twenty-one students (17 women, age range = 19–53 years, $M = 33$; $SD = 12.3$) from the UNED took part in the experiment. All of them had normal or corrected-to-normal vision and received course credits for their participation. These participants had previously participated in Experiment 3 (target presentation of 40 ms) in Study 1.

Stimuli and apparatus Stimuli and apparatus were identical to those used in Experiments 1 and 2.

Procedure and design The procedure and design were identical to Experiments 4 and 5, with the exception that the target was presented for 80 ms.

Results and discussion

Subjective awareness A target duration of 80 ms produced a marginal use of *no perception* reports (rating 1: 3% of the trials) whereas *clear perception* (rating 4) was the most used rating (46% of the trials) (see Table 2 and Fig. 4a). In addition, *almost clear perception* (rating 3) was significantly used in 30% of the trials, whereas *weak perception* was also frequently used (rating 2: 21% of the trials). Thus, intermediate ratings were reported in 51 % of the trials (see Fig. 4a and b).

A repeated-measures ANOVA on the mean use of awareness reports at different mask organizations was again conducted. Results showed that Mask Organization did not interact with Awareness ($F(7,131) = .37$, $MSE = 8.96$, $p = .912$, η^2_p

$= .01$), suggesting that the different mask organizations did not produce different awareness distributions.

Detection task Detection accuracy was significantly above chance level (.25) when participants reported *no perception* (rating 1: .54; $t(14) = 3.18$; $p = .007$), whereas accuracies for the remaining awareness levels were as follows: rating 2 = .96, rating 3 = .98, and rating 4 = .97 (see Table 2 and Fig. 4c).

Detection accuracies were analyzed using a linear mixed-effects model, Mask Organization and Awareness were introduced as fixed effects to the model and Subjects as random variable. Results showed a significant effect for Mask Organization ($F(5,382) = 4.65$, $p < .001$), suggesting that different mask types produced different accuracy levels. The exploration of pairwise comparisons (Bonferroni corrected) showed that differences in accuracies were observed between the 100% and 50% ($p = .047$), 60% ($p < .001$) and 70% ($p = .028$) organization masks. A significant effect for Awareness ($F(3,382) = 85.61$, $p < .001$) showed that different awareness categories produced different accuracy levels, whereas Mask Organization interacted with Awareness ($F(15,382) = 3.19$, $p < .001$). Pairwise comparisons (Bonferroni corrected) showed that all significant accuracy differences occurred exclusively at rating 1 (*no perception*). Specifically, 100% mask organization produced lower accuracy performances when compared to all other mask organizations (all $ps < .001$). Individual mean accuracies at each awareness rating were subjected to a one-way ANOVA in order to conduct trend analyses for Awareness. Polynomial contrasts produced both a linear ($F(3,70) = 13.48$, $MSE = .03$, $p < .001$, $\eta^2_p = .48$) and a quadratic ($F(3,70) = 23.07$, $MSE = .03$, $p < .001$, $\eta^2_p = .48$) trend. A visual inspection of detection performances across the awareness scales (Fig. 4c) showed an abrupt increase in accuracy levels from awareness rating 1 to awareness rating 2, thus following a non-gradual pattern.

Identification task Identification accuracy was above chance level (.50) when participants reported *no perception* (rating 1: .67; $t(14) = 2.89$; $p = .012$), whereas accuracies for the remaining awareness levels were as follows: rating 2 = .76, rating 3 = .91 and rating 4 = .91 (see Table 2 and Fig. 4c).

Identification accuracies were also analyzed using a linear mixed-effects model in order to avoid listwise deletion of missing values. Mask Organization and Awareness were introduced as fixed effects to the model and Subjects as random variable. Results showed no significant effect for Mask Organization ($F(5,382) = 0.88$, $p = .495$), indicating that different mask types did not produce different accuracy levels. A significant effect for Awareness ($F(3,382) = 24.30$, $p < .001$) suggested that different awareness categories produced different accuracy levels, whereas Mask Organization did not interact with Awareness ($F(15,382) = 1.06$, $p = .391$). Individual mean accuracies at each awareness rating were subjected to a

one-way ANOVA in order to conduct trend analyses for Awareness, which showed that accuracy levels increased linearly across the awareness scale (linear trend: $F(3,70) = 16.20$, $MSE = 0.04$, $p < .001$, $\eta^2_p = .20$). Therefore, a longer target presentation of 80 ms was associated with a linear increase in identification accuracies.

Here, a stimulus presentation of 80 ms also showed a divergence in objective performances between the stimulus processing at *energy* versus *feature* levels. Whereas this target duration was linked to an abrupt increase in accuracy performances at stimulus *energy level* (i.e., detection task) from rating 1 (*no perception*) to the other awareness categories, identification performances increased following a linear pattern.

Additionally, Mask Organization factor was significant for the detection task, suggesting a lower accuracy performance for 100% mask organization. Mask Organization $\times$ Awareness interaction showed that lower accuracy performances were all produced at rating 1 (*no perception*). Specifically, the most organized mask (100%, which formed vertical or horizontal line patterns) produced a stronger masking of the stimulus as suggested by significantly lower detection accuracy performances.

Study 2: Interim discussion

When *I-shaped* and *H-shaped* targets were presented for 27 ms (Exp. 4), visibility of the targets was very restrictive, as shown by a predominant use of *no perception* (rating 1: 51% of trials), and *weak perception* (rating 2: 39% of the trials) reports. The total number of intermediate ratings did not reach half of the reports (47%) for this target presentation. A target presentation of 53 ms (Exp. 5), on the other hand, produced a very high number of intermediate awareness ratings (74% of the trials), both *weak* (rating 2: 48% of the trials) and *almost clear* (rating 3: 26% of the trials) perceptions being used in a significant number of trials. Finally, *clear perception* (rating 4) was the most used rating (46% of the trials) at the longest target duration of 80 ms (Exp. 6), but *almost clear* (rating 3) and *weak* (rating 2) perceptions were very frequently used (30% and 21% of the trials, respectively) (see Table 2 and Fig. 4a and b).

Objective detection performance showed that a target presentation of 27 ms was too restrictive for producing a linear increase in accuracies across awareness categories, whereas the longer target durations of 53 and 80 ms produced a dichotomous, non-linear increase in accuracies. On the other hand, identification performances showed that the target presentations of 27 and 53 ms were too restrictive for producing any increase in accuracies across awareness categories, yet accuracies increased following a linear pattern at the longer SOA of 80 ms (see Table 2 and Fig. 4c). Thus, here we found a divergence of objective accuracy performances as a factor of target duration for detection and identification tasks. In addition, when the target was presented for an intermediate

duration of 53 ms (Exp. 5), a particular scenario emerged: target localization was easy, whereas feature identification was very challenging. Thus, it may be possible that at this intermediate target duration, reported subjective awareness was influenced to some extent by subjective perceptions associated with the lower-level (detection) task.

Even though any particular comparison between experiments should be cautiously interpreted, as the experimental design in the present study was between-subject, it could be proposed that different awareness rating ranges map differently between experiments. For example, when looking to detection accuracies between Experiment 4 and Experiment 5, it could be suggested that 1–2 ratings in Experiment 5 map onto the range of 1–4 ratings in Experiment 4. However, this scenario would require similar detection accuracies for rating 4 (Exp. 4) and rating 2 (Exp. 5) and the same non-linear trend for both detection and identification accuracies in Experiment 5. Very low detection accuracies at rating 4 (Exp. 4) and low identification accuracies across all awareness ratings (i.e., in the 1–4 range) in Experiment 5 seem to argue against different awareness ratings mapping into different awareness ranges between these experiments.

Overall, results in Study 2 suggest that detection performances are very sensitive to small variations in stimulus presentations, in line with the results in Study 1. Interestingly, both subjective and objective awareness measures suggest that stimulus processing at the *feature level* may follow a graded pattern at longer stimulus presentations (target presentation of 80 ms).

In addition, accuracy levels were above chance level for stimulus detection when observers reported *no perception* of the stimulus (rating 1) at both 27-ms and 53-ms target presentations, but they were at strict chance level for the identification of target features. This suggests that stimulus detection but not identification is influenced by unconscious processing of the target at stimulus durations of 53 ms and below.

In line with the results in Study 1, different mask organizations did not produce either different awareness distributions or accuracy levels across the three different target durations (with the exception of detection accuracies at the longest target duration of 80 ms for the 100% mask). Overall, mask organization results in Study 2 suggests that, even though the masking design was successful in producing different awareness levels (as shown by both subjective and objective awareness measures), each mask organization was not associated with specific awareness levels.

Combined analysis of Experiments 2 and 4

With the intention to explore differences in the distribution of the awareness ratings between Experiment 2 and Experiment 4, which shared the same target duration of 27 ms and the same group of participants but involved different tasks, a 2

(Experiment: 2 vs. 4) $\times$ 6 (Mask Organization: 100%, 90%, 80%, 70%, 60%, 50%) $\times$ 4 (Awareness: 1, 2, 3, 4) repeated-measures ANOVA was conducted (due to the different number of trials in Exps. 2 and 4, number of trials was transformed to percentage of trials). Results showed a significant main effect for Awareness ($F(3,66) = 13.76$, $MSE = 13841.31$, $p < .001$, $\eta^2_p = .38$), which indicated that the different ratings were not uniformly used. Importantly, a significant Experiment $\times$ Awareness interaction ($F(3,66) = 3.87$, $MSE = 3944.42$, $p = .032$, $\eta^2_p = .15$) suggested differences in the awareness reports distributions between studies (see Figs. 3 and 4). Pairwise comparisons (applying Bonferroni correction) showed significant differences between experiments in the use of rating 1 ($p = .019$; fewer *no perception* reports in Exp. 2) and rating 3 ($p = .038$; fewer *almost clear* reports in Exp. 4), but not in the use of rating 2 ($p = .446$) and rating 4 ($p = .263$). In addition, a significant three-way interaction ($F(15,330) = 2.73$, $MSE = 78.19$, $p = .014$, $\eta^2_p = .11$) suggested that the use of awareness ratings between experiments varied as a function of the organization of the masks. Pairwise comparisons (applying Bonferroni correction) showed that significant differences between experiments in the use of rating 1 occurred at all mask organizations (all $ps < .05$) except for 80 % ($p = .054$) and 100% ($p = .138$) masks, whereas significant differences between experiments in the use of rating 3 occurred at all mask organizations (all $ps < .05$) except for 100% ($p = .138$) mask. All other interactions were non-significant. Thus, since experiments in Study 1 involved only a detection task whereas experiments in Study 2 also involved an identification task, it could be argued that a criterion shift may have occurred in the use of the subjective awareness scale between studies. Furthermore, the targets presented in the two studies were different. When the task included target identification of *I*- and *H-shaped* targets (Exp. 4), we found a significant increase in *no perception* (rating 1) reports, which might be explained due to differences in target attributes (i.e., spatial frequency, contrast, saliency). Additionally, the identification task involved further attentional demands in order to discriminate target features, which might be responsible for the significantly fewer reports of *almost clear perceptions* (rating 3) in Experiment 4. Thus, differences in the awareness rating distribution between experiments may suggest that the use of awareness scales could be affected by criterion shifts due to task demands.

General discussion

In the present study, we conducted a series of experiments in order to explore the nature of visual awareness at the *low end* (i.e., *energy* and *feature levels*) of the stimulus-processing hierarchy. Whereas previous studies have used a wide range of target durations (Anzulewicz, Asanowicz, Windey,

Paulewicz, Wierchoń, & Cleeremans, 2015; Binder et al., 2017; Windey, Gevers, & Cleeremans, 2013) or SOAs (Kiefer & Kammer, 2017) in order to study the *emergence* of visual awareness for increasing stimulus intensities, here we intended to explore the graded or dichotomic nature of visual awareness at specific target durations. With this intention, we used a novel masking design that manipulated the regularity of the mask in order to produce different awareness levels at specific target durations. Even though each mask organization did not produce a specific awareness state associated with it (except for detection accuracies when participants reported no perception at the longer target duration of 80 ms), the masking design proved successful in producing different awareness levels at different target durations.⁵

According to our predictions, if visual awareness at stimulus *energy* and *feature* levels is graded, we would expect a significant number of intermediate awareness ratings across the different target durations used in our study. Consistent with this, we found that *intermediate ratings* were used in more than 50% of the trials in Experiment 2 (62% of trials), Experiment 3 (59% of trials), Experiment 5 (74% of trials), and Experiment 6 (51% of trials). More specifically, *weak perception* (rating 2) was significantly used in 25% or more of the trials in Experiment 2 (44%), Experiment 3 (25%), Experiment 4 (39%), and Experiment 5 (48%), whereas it was very frequently used in Experiment 1 (22.5%) and Experiment 6 (21%). *Almost clear perception* (rating 3) was used in a significant number of trials in Experiment 3 (34%), Experiment 5 (26%), and Experiment 6 (30%), whereas it was very frequently used in Experiment 2 (18%). Importantly, objective accuracy performances showed that a target presentation of 27 ms (Exp. 2) produced a linear increase in detection accuracies across the awareness-scale categories, whereas a stimulus duration of 80 ms showed a similar linear increase in identification accuracies. Thus, the results from both subjective-awareness measures and objective accuracy performance suggest that visual awareness may be graded at stimulus *energy* and *feature* levels.⁶

Additionally, accuracy results for the detection task suggest that objective detection performance is very sensitive to small changes in target durations at stimulus *energy level*, which is

⁵ Informal tests conducted before the formal experiments were done presenting the mask in a sequential order (from most to less organized), which seemed adequate in producing specific awareness states associated with each mask organization, the sequential design possibly facilitating this association. Masks in the formal experimental sessions, however, were randomly presented in each trial, a randomization that might blend together different masking strengths (random variations in alertness across trials should be also taken into account).

⁶ In order to explore whether practice effects were having some influence in the observed results, we conducted further analyses for awareness rating distributions and objective accuracy performances between experimental blocks at each experiment. These further analyses are presented in the Supplementary Material, and argue against practice effects influencing or explaining the obtained pattern of results.

not accompanied by subjective awareness experiences. Indeed, a stimulus presentation of 27 ms (Exp. 2) produced a proportional (i.e., linear) increase in accuracies at increasing awareness levels, whereas all target presentations longer than 27 ms (Exps. 3, 5, and 6) produced an abrupt, non-linear increase in accuracy levels from rating 1 (*no perception*) to rating 2 (*weak perception*). This pattern is in line with previous results showing that subjective awareness increases more slowly than objective accuracy levels (Sandberg, Bibby, Timmermans, Cleeremans, & Overgaard, 2011). Interestingly, the abrupt increase in accuracies was in all cases observed when moving from rating 1 (*no perception*) to rating 2 (*weak perception*). Whereas previous evidence using increasing stimulus intensities have shown that the PAS scale is the most exhaustive subjective measure for capturing participants' relevant subjective experiences (see Overgaard & Sandberg, 2012, for a review), here, the observed pattern of results for the detection task opens an interesting question for future research. Specifically, elucidating whether the introduction of further scale steps between *no perception* and *weak perception* ratings (such as “edge of visibility” or “barely visible”) would produce a more exhaustive subjective scale, as measured by subjective reports-objective accuracy correlations, may yield interesting results. On the other hand, detection accuracy was also sensitive to the shape of the target, as shown by the dissociation in the pattern of results for the same participants in the detection of *light squares* (Exp. 2) and *I-shaped* and *H-shaped* targets (Exp. 4) at the same target duration of 27 ms. In Experiment 2, accuracies were significantly different at each awareness category and increased following a linear trend, whereas in Experiment 4 accuracies were low at all awareness categories. It is noteworthy that the shape of *light squares* and the *I-shaped* and *H-shaped* targets differed in some crucial attributes (i.e., spatial frequency, contrast, and degree of organization). In addition, the *light square* had both interior and exterior edges, producing a more salient shape than the *I-shaped* and *H-shaped* targets. Therefore, the different mask patterns may have disrupted target detection differently, all the factors above possibly influencing detection accuracy performances between experiments. Interestingly, results in the present study seem to converge with previous studies by Uttal (1975, 2014) showing that the detection of dotted forms may be influenced by the degree of organization of the figure: regular forms (such as a square) are better detected than irregular forms (such as a parallelogram), and also that most organized forms are better detected than less organized forms.

Identification of *I-shaped* and *H-shaped* targets showed that a target presentation below 53 ms (i.e., 27 ms and 53 ms) was too short for producing any increase in accuracies across awareness categories (accuracy levels did not exceed 68% performance in any of the awareness categories of this two experiments, see Table 2b and Fig. 4c), thus suggesting a

divergence of objective accuracy performances as a factor of target duration for detection and identification tasks. Consistent with previous findings (Grill-Spector & Kanwisher, 2005; Kiefer & Kammer, 2017; VanRullen, & Thorpe, 2001), the presence of a stimulus seems rapidly accessible to consciousness, while additional discrimination or identification processes require crossing significantly higher awareness thresholds. In this regard, Koivisto, Grassini, Salminen-Vaparanta, and Revonsuo (2017) recently conducted an event-related potential (ERP) study that examined basic detection and more complex identification processes. Their results showed that conscious detection specifically modulated ERP activity between 200 and 300 ms, whereas conscious identification was associated with widespread cortical activity from 400 ms onwards. There is also some functional magnetic resonance (fMRI) evidence pointing towards an early involvement of early posterior visual areas in rapid stimulus detection, while further identification processes involve the recruitment of additional brain regions within the ventral stream and the fronto-parietal network (Zachariou, Klatzky, & Behrmann, 2014; see also Straube & Fahle, 2011). According to the proposal by Dehaene, Changeux, Naccache, Sackur, and Sergent (2006), weak strength stimuli are processed in extrastriate cortices, whereas activation spreads to fronto-parietal networks for those stimuli that are sufficiently strong. Therefore, very short stimulus presentations in our study may have activated early visual areas, which might be enough for basic level processing. Instead, longer stimulus presentations would be needed to discriminate between meaningful stimuli. Thus, from a methodological point of view, the introduction of the same SOA range in the exploration of visual awareness at both low- and higher-level tasks may introduce a confound in the observed results, since stimulus low-level processing (i.e., presence/absence, detection) shows a much shorter awareness threshold combined with a high sensitivity to small changes in target presentation times. Interestingly, accuracy levels were above chance level for stimulus detection when observers reported *no perception* at both SOA 27 ms (Exp. 4) and 53 ms (Exp. 5) (and also in Exps. 1, 2, and 3), but they were at strict chance level for the identification of target features in these two experiments. This suggests that stimulus detection but not identification is influenced by unconscious processing of the target at SOAs 53 ms and below.

Looking at subjective awareness distributions in the two different studies, it may be argued that participants used the subjective rating scales rather differently depending on task demands. On the one hand, the objective task differed between experiments: In Study 1 participants performed a detection task, whereas the main task in Study 2 was the feature identification task, even though participants also indicated the location of the target. Thus, the criterion contents for reporting awareness levels may have changed according to the criterion contents used in the objective task, from *clarity* being

associated with the detection of the target to *clarity* being associated with the identification of stimulus features (Bachmann, 2015; Sackur, 2013). Significant differences in awareness distributions between Experiments 2 and 4 (same stimulus duration and group of participants but involved different tasks) seem to suggest that this criterion shift may have occurred. Indeed, the identification task involved further attentional demands that are not needed for a mere detection of the stimulus. This attention to target features seems to specifically affect the *almost clear perception* (rating 3), suggesting that a more degraded version of the stimulus may be perceived when *almost clear* ratings are reported in the detection task. In addition, a deeper look at different awareness distributions in Study 2 shows that, when visibility of the target was very restrictive (Exp. 4, very low detection and identification performances across the awareness scale), *clear* and *almost clear* ratings were still used (the same pattern was observed at the restrictive Exp. 1 condition). This suggests that some participants might show a tendency to use all available categories when presented with a four-point scale. Furthermore, when the target was presented for an intermediate duration of 53 ms (Exp. 5), a particular scenario emerged: target localization was easy, whereas feature identification was still very challenging. Thus, at this intermediate target duration, subjective awareness distribution may have been critically influenced by subjective perceptions associated with the lower-level (detection) task.

We consider that criterion-shift confounds should be carefully taken into account in future research on the *levels of processing* framework, as participants may recalibrate the meaning of the different awareness categories according to task demands. Note that, consistent with previous studies (Anzulewicz et al., 2015; Binder et al., 2017; Windey et al., 2013), in the present study the instructions for the PAS scale were identical for both the lower-level (detection) and the higher-level (feature identification) tasks. The absence of specific instructions on the use of the awareness scale at different levels of stimulus processing, however, may lead to criterion confounds, as some participants in the lower-level task may report their awareness of the stimulus according to both lower (i.e., location) and higher (feature, identity) levels of processing (e.g., reporting *clear perception* only when clearly perceiving both the location and the identity of a target), whereas other participants may report their awareness of the stimulus based only in a lower-level stimulus perception (i.e., when clearly perceiving the location, but without accessing higher features of the stimulus). Conversely, some participants in the higher-level task may show the inverse tendency, that is, to inform their awareness of the stimulus based in (or influenced by) the lower level of stimulus processing (i.e., location), while other participants may report their awareness of the target strictly based on the higher-level attributes of the stimulus (i.e., feature, identity). In order to overcome criterion-

shift confounds within the levels of processing framework, “clarity” at the different levels of stimulus processing should be exhaustively defined, and participants should be thoroughly instructed on the use of the awareness scale at the different levels of stimulus processing/tasks. Moreover, the exploration of PAS reports and accuracy performances at the individual level (see [Supplementary Material](#)) shows variability in both the use of the PAS scale and objective task performances. Further work is needed with a focus on this question and a larger sample size to establish the precise nature of the relationship between these measures.

Additionally, we found different scenarios where subjective ratings did not accord with objective performances (i.e., above-chance-level accuracies for *no perception* ratings, very high detection accuracies for *weak perception* ratings, or low detection and identification performances for *almost clear perception* ratings). The debate over subjective versus objective measures of awareness has a long history within consciousness research (Merikle, Smilek, & Eastwood, 2001; Persuh, 2018), and it seems that the two different measures reflect different aspects of the processing of stimulus information depending on task demands. When participants report their subjective awareness (e.g., PAS scale), they seemingly report on the quality of their subjective experience (Sandberg et al., 2010). However, it has been also proposed that PAS ratings do not reflect direct reports on visibility, but should rather be interpreted as an awareness of the fact of seeing (i.e., a metacognitive measure of awareness; Wierchoń, Paulewicz, Asanowicz, Timmermans, & Cleeremans, 2014). Metacognition refers to the ability of humans to evaluate their own internal cognitive processing (Fleming & Lau, 2014), and relationship between metacognitive judgments and perceptual awareness are a current matter of debate (Maniscalco, Peters, & Lau, 2016). Evidence shows that, whereas perceptual decisions are equally driven by response-congruent and response-incongruent evidence, confidence levels are largely insensitive to the level of response-incongruent evidence (Maniscalco et al., 2016; Zylberberg, Bartfeld, & Sigman, 2012). In addition, studies on confidence and perceptual decisions have presented evidence of dissociations between confidence ratings and accuracy, correct responses being systematically observed at low confidence levels whereas incorrect responses are observed at very high confidence levels (Graziano & Sigman, 2009). In our opinion, the extent to which perceptual awareness scales (e.g., PAS) measure the quality of subjective experiences, and to which extent these ratings are influenced by metacognitive or confidence judgments is an important question for future research. In addition, the analysis of objective measures of awareness might benefit from the introduction of forced-choice paradigms that allow the calculation of signal detection theory (SDT) measures, thus teasing apart participants’ sensitivity from response bias (Fleming & Lau, 2014).

Conclusions

In sum, our results show that visual awareness at *energy* and *feature levels* of stimulus perception may be graded at specific individual target durations, which provides new evidence within the *levels of processing* framework (Windey & Cleeremans, 2015). Furthermore, we found a divergence in the results for detection and identification processes. Since the stimulus presence at the energy level is rapidly accessible to consciousness, a short target presentation (or target presentation range) should be preferred when studying the nature of the emergence of visual awareness at the lowest level, as accuracy levels are very sensitive to small changes in stimulus duration. Conversely, studies designed to examine more complex stimulus discrimination or identification processes would benefit from using longer stimulus durations.

Overall, the results of the present study are consistent with previous studies (Del Cul et al., 2007; Kiefer & Kammer, 2017; Overgaard et al., 2006; Windey & Cleeremans, 2015) in emphasizing that visual awareness might be highly dynamic, crucially depending on experimental factors such as task (detection vs. identification) and stimulus characteristic (i.e., energy, feature, meaning). Finally, and in order to overcome criterion-shift confounds within the *levels of processing* framework, “clarity” at the different levels of stimulus processing should be exhaustively defined, and participants should be thoroughly instructed on the use of the awareness scale and the meaning of “clarity” at the different levels of stimulus processing or tasks.

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