The graded and dichotomous nature of visual awareness.

Bert Windey [1, 2, 3], Astrid Vermeiren [1, 2, 3], Anne Atas [1, 2, 3], Axel Cleeremans [1, 2, 3]

[1] ULB Neuroscience Institute (UNI), Université Libre de Bruxelles, Building C / Campus Erasme CP 602, 808, Route de Lennik, 1070 Bruxelles, Belgium.
[2] Center for Research in Cognition and Neurosciences (CRCN), Université Libre de Bruxelles, CP 191, Avenue F.-D. Roosevelt, 50, 1050, Bruxelles, Belgium.
[3] Consciousness, Cognition and Computation Group, Université Libre de Bruxelles, CP 191, Avenue F.-D. Roosevelt, 50, 1050, Bruxelles, Belgium.

Mail corresponding author: bwindey@ulb.ac.be.

Keywords: Consciousness, Awareness, Vision, Psychophysics, Graded, Dichotomous.

ABSTRACT

Is our visual experience of the world graded or dichotomous? Opposite pretheoretical intuitions apply in different cases. For instance, when looking at a scene, one has a distinct sense that our experience has a graded character: One cannot say that there is no experience of contents that fall outside the focus of attention, but one cannot say that there is full awareness of such contents either. By contrast, when performing a visual detection task, our sense of having perceived the stimulus or not exhibits a more dichotomous character. Such issues have recently been the object of intense debate because different theoretical frameworks make different predictions about the graded vs. dichotomous character of consciousness. Here, we review both relevant empirical findings as well as the associated theories (i.e., local recurrent processing versus global neural workspace theory). Next, we attempt to reconcile such contradictory theories by suggesting that level of processing is an oft-ignored but highly relevant dimension through which we can cast a novel look at existing empirical findings. Thus, using a range of different stimuli, tasks and subjective scales, we show that processing low-level non-semantical content results in graded visual experience, whereas processing high-level semantical content is experienced in a more dichotomous manner. We close by comparing our perspective with existing proposals, focusing in particular on the partial awareness hypothesis.

1. INTRODUCTION

Is conscious experience graded or all-or-none? Different sources of evidence yield different answers to this deceptively simple question. From an introspective perspective, it often seems that the contents of phenomenal experience exhibit a graded nature. Consider for instance one's experience of attending a cocktail party. While you are focused on the conversation that is taking place between your friends, you are also aware, in different degrees, of the many other streams of perceptual information that reach your senses: The faint smell emitted by the all-too-distant zakouskis you crave; the rumblings of your stomach, the noise produced not only by the many other conversations that are taking place but also by a nearby cellphone ringing off; the beautiful light of the settling sun; the mostly familiar faces of your colleagues; the itch on your neck, no doubt a result of your eating too much shrimp last night, at this very same spot, during another conference party. These many contents all merge together to form James' "stream of consciousness". In other cases, however, the contents of conscious experience appear to exhibit an all-or-none character. For instance, in a change blindness situation, I may all of a sudden finally notice the change I had been looking for. Or I may suddenly notice the fact that someone is calling my name in a crowd.

Thus, it would seem that conscious experience can either be graded or binary depending on a host of factors such as the nature of the stimulus, the direction of our attentional focus, the characteristics of the task we have to perform or the context in which we find ourselves. Other important factors appear to be pre-theoretically important in exploring this issue. One such factor concerns the putative mechanisms through which graded or dichotomous phenomena can be produced. This is tricky, for continuous, graded changes (i.e., in temperature) can result in all-or-none transitions (i.e., water turning into ice), just as continuous changes (i.e. in the loudness of a sound) can be produced from the operation of fundamentally all-or-none elements (i.e., a binary-coded digital signal as stored on a compact disk). These considerations all highlight the importance being precise in specifying which aspect of cognitive processing is thought to be graded or all-or-none: a neural representation? One's subjective experience of the stimulus? A participant's verbal report?

It is worth noting that debates between gradedness and dichotomy occur in various fields of psychology, among which many in developmental psychology, for example in word acquisition [1] or the representation of number [2]. Recently, whether visual experience is graded or dichotomous has been the object of intense debate. Looking around, do we gradually become more aware of things while accumulating sensory information about them? Or is consciousness more something of an on-off phenomenon: either we perceive something, or we don't, without intermediate states of awareness? Not only do both alternatives have intuitive appeal, also experimental evidence for both views has accrued over the years.

As pointed out, it is important to distinguish different aspects of cognitive processing which could be graded or dichotomous: the input, the representation, the subjective experience of the input/representation and the behavioural report of the experience. One could be looking at graded (slowly changing shades of a colour) or binary material (is a photo a family member or not). Also the representational level could be graded or dichotomous: On a neural level, the amount of in- and outflow in the ion channels and neural firing rates (i.e., the frequency of action potentials) are clearly graded, just as the number of neurons involved during a task. Conversely, the occurrence of an action potential is all-or-none. Our subjective experience can then consist of different states of intermediate perceived clarity, or we can either see things or not. Finally, a report through a single button press in a forced-choice situation has always an all-or-none characteristic, because no matter how vague the input or experience was, one has to decide on a specific conclusive response. We will thus have to look at a series of responses to find out whether graded or dichotomous response patterns arise. In this review, we show how the confusion between graded and dichotomous visual experience (i.e., the subjective experience aspect) is at least partially the byproduct of the experimental manipulations used so far (i.e., the input aspect). The notable physicist Werner Heisenberg has been quoted for saying that “what we observe is not nature itself, but nature exposed to our method of questioning”. This statement seems to be particularly relevant to the debate concerning the graded versus dichotomous character of conscious experience. Indeed, it appears that these two hypotheses have mostly been verified with different stimuli and tasks, respectively. Perhaps using consistently different methods has led us to two different conceptualisations of the same phenomenon. To make matters worse, apart from the fact that asking people about their visual experience of something might change the experience itself, subjective reports by definition need to be provided through some form of scale or measure. It is conceivable that the way in which people are asked to indicate their perception influences how they report their visual experience. In this review, we will discuss in detail how the understanding of the nature of visual experience could benefit from taking into account these differences in experimental manipulations and subjective scales of awareness.

We will start by presenting studies that used different types of stimuli and tasks and thus provided evidence for either the graded or the dichotomous account, together with their theoretical frameworks. Next, we will address how subjective scale measures may have contributed to the confusion. We will then formulate a proposal that begins to integrate the graded and the dichotomous accounts. In short, we suggest that both these contradictory frameworks may turn out to be correct when this difference in stimuli or tasks, and more specifically, the level of processing of these stimuli that is associated with the task, is taken into account. After presenting recent studies that verified the validity of this proposal, we will frame these results in a broader context and formulate ideas for further research.

2. GRADEDNESS OR DICHOTOMY

Indications for gradedness or dichotomy

A number of behavioral data patterns have been examined in the literature to obtain evidence for a graded or a dichotomous nature of awareness: psychophysical curves, the distribution of subjective judgments, and the accuracy for different reported levels of subjective visibility. First, psychophysical curves can be computed if for example stimuli are presented for several different durations (e.g., 10, 20, 30, …, up to 80 ms). For each and every stimulus duration the average performance or visibility can be plotted, and we can verify whether there is a steady or a more sudden increase in steepness of the resulting curve. Second, also the distribution of subjective visibility ratings can be examined if participants give such judgments on every trial. A distribution can be unimodal, implying that participants report visibility along the whole spectrum of the scale: stimuli they haven't seen at all, stimuli they clearly saw, but also stimuli which were "more or less" visible. The distribution can also be bimodal, for example when participants only report to have seen the stimuli either not at all or completely clearly. Third, participants' accuracy level has been compared for every subjective rating they gave themselves. One could for example verify whether for every higher step on the subjective scale, also an increase in performance can be observed. In the next two parts we will present behavioural data using these three markers along with neuroimaging data that backed either the graded or the dichotomous account, together with respective theoretical frameworks.

Graded awareness

A number of studies used a psychophysical design, presenting geometrical figures for different durations. In Overgaard, Feldbaek Nielsen and Fuglsang-Frederiksen [3], participants were asked to report individual features of the geometrical figures, such as shape, colour and position on the screen. Additionally, they had to indicate the degree of clarity of the figure stimuli that were presented for 16 ms up to 192 ms. Participants were prompted to use a scaling ranging from "no experience at all" to "an absolutely clear image", but they were told that they could create any categories with which they felt comfortable. All participants ended up using a scale with four degrees of visibility. When the average visibility was plotted for each stimulus duration, the psychophysical curves indicated that increases in stimulus duration were accompanied by a gradual increase of perceived clarity. This result was confirmed in two other studies with the same stimuli [4,5]. In the latter paper, curve fitting was used to characterise the psychophysical curves. The models had four parameters. Parameters *a* and *b* represented the lower and upper boundary of the sigmoid curves, respectively. Parameter *c* represented the inflexion point. Parameter *d* represented the steepness of the curve, which is the extent to which the curve is (non-) linear. According to the authors, a dichotomous nature of awareness would imply that the *d* parameter for the steepness of the sigmoïd curve would be very close to zero. However, *d* turned out to be significantly different from zero. If we take the range of the durations that are associated with chance performance up to ceiling performance (for the feature report task) and from minimal to maximal visibility (for the subjective scale ratings) as the relevant time-window, this implies that the curves had a more gradually increasing slope than a step function over this time-window. Compatible findings were reported in Overgaard, Rote, Mouridsen and Ramsoy [6]. Here, participants were asked to perform an orientation categorisation task on simple textures with two different orientations that were again presented for different durations. To assess stimulus clarity as subjectively experienced by the participants, the subjective scale was composed of four scale points that were all individually labeled (Perceptual Awareness Scale or PAS; also cf. Overgaard et al., 3). Labels ranged from “no experience at all” over “brief glimpse” and an “almost clear experience” to a “clear experience” of the stimulus that has just been presented. A regression analysis confirmed a gradual rise of subjective visibility with increasing stimulus strength. The authors calculated furthermore that every increase of 10 ms stimulus duration made it four times more likely that the participants would give a PAS rating of 3 or 4.

Apart from the psychophysical curves we can also examine the distribution of subjective ratings. Even though the PAS scale comprises just four scale points, which entails that it is hard to speak of distributions in the statistical sense, one can look at the frequency of each rating. In both Overgaard et al. [3] and Overgaard et al. [6], as well as in Sandberg et al. [4], the exact frequency was not explicitly reported, but from the data we can see that all scale points were used. This implies that participants do have intermediate states of awareness, which was taken as evidence for a graded nature of awareness. Moreover, in these studies, the average accuracy was compared for each scale point. Every PAS scale point is accompanied by a different accuracy level, which according to the authors suggests that these scale points are not just response biases induced by the scale, but imply an actual difference in processing. Intermediate scale point ratings would therefore stem from genuine intermediate states of awareness.

An fMRI study verified whether such intermediate states could also be identified at the neural level [7]. The same geometrical stimuli as mentioned above were presented for 33 ms up to 100 ms, and participants scored the trial-by-trial visibility through a version of the PAS scale with three steps (no perceptual experience of the stimulus, glimpse-like perceptual experience, and clear perceptual experience). Participants here felt most comfortable to map their subjective clarity on three steps, and used each of three scale points for about one third of the trials. This replicates the previous behavioural findings that people use intermediate scale points to rate graded states of awareness. At the neural level, different degrees of perceived clarity (corresponding to each scale point including the intermediate point) were accompanied by distinctly different brain activation patterns. Importantly, within the widespread network activated during clear perceptual experience (parietal cortex, prefrontal cortex, premotor cortex, supplementary motor areas, insula and thalamus), the degree to which activation was found in this network changed as a function of the degree of reported clarity. From the behavioural and neuroimaging data the authors concluded that subjective visual experience is graded.

Several other neuroimaging studies have been carried out with basic visual stimuli that are processed in early visual cortices (for example colour, orientation, etc. as described above). We note that studies presenting small disks [8], or moving dots as stimuli [9], or inducing phosphenes using TMS [10] found feedback-projections to early visual cortex to be necessary for conscious perception. Other studies that presented half-circles [11] or texture grating stimuli [12,13] found recurrent processing in or between early visual regions to underlay awareness, leading Lamme and colleagues to the conclusion that consciousness should simply be defined as recurrent processing [14,15]. Overall, it seems that studies with basic visual stimuli have usually resulted in graded behavioural and neural data patterns, and in evidence for a relation between posterior feedback projections or local recurrent processing and visual awareness.

Dichotomous or all-or-none awareness

A large body of psychophysical experiments, however, have been carried out with very different sets of stimuli and tasks, and have reported evidence to the contrary. A series of experiments presented steeply rising psychophysical curves [16-18]. Participants had to compare briefly flashed digits to 5, which were postmasked with a variable delay from 16 ms up to 100 ms, thus rendering the digit on average more visible with increasing SOA. On every trial, they rated the extent to which the stimulus was perceived by moving a cursor over a scale that ranged from minimal to maximal visibility. Only these two labels were indicated, but the scale consisted of 21 possible positions, potentially allowing for a more fine-grained discrimination of subjective states (i.e., Sergent and Dehaene Scale, SDS, 19]. When objective task performance on the number categorisation task and average subjective visibility was plotted against stimulus duration, all three studies showed steep slopes for both curves, due to a sharp rise in performance and subjectively experienced clarity around the visibility threshold. Therefore non-linear regression models provided a good fit to the data [16,17]. In Del Cul et al. [16] the increase in average subjective visibility was compared for all mask delay pairs. They demonstrated that the increase in visibility from 33 to 66 ms was significantly larger than from 16 to 33 and 66 to 83 ms, which according to the authors was suggestive for non-linearity.

Strong evidence for the dichotomous account was obtained by analyzing the distribution of the subjective ratings on the SDS scale. Despite the continuous nature of the scale, allowing for fine-grained discriminations in perceived clarity, the distribution of the ratings was consistently bimodal in a series of studies. Even though participants have as such the possibility to indicate intermediate levels of clarity, they situate their judgments at the extreme ends of the scale, rating their experience of the stimulus as either entirely invisible or entirely visible. These results were found with the number categorisation task discussed above [16,17] and in two studies using the attentional blink paradigm [19,20]. In the attentional blink paradigm participants need to report visibility on a word target (T2) which has to be compared against four-letter strings of consonants that all appear in a rapid serial visual presentation. In some of the trials they also need to report the two central letters of an “XOOX” or an “OXXO” string (T1). T2 is perceived or remains unperceived depending on the temporal distance between T1 and T2. A computational model successfully simulated this attentional blink paradigm [20]. The architecture of the model links a series of distributed networks performing a specific kind of processing together through a central network of high-level areas, in its entirety called “the global workspace”. When the first target is presented, it occupies the workspace, leading to conscious reportability of the stimulus. The second target therefore fails to be broadcasted to a similar extent through the workspace, not reaching a similar state of reportability. Importantly, the model predicted an all-or-none transition from an unconscious to a conscious state. People would be either in an unconscious state corresponding to “invisible” subjective reports, or in a conscious state and giving “visible” subjective reports. An earlier model already showed how global workspace neurons coactivate during effortful cognitive tasks [21]. Additional support for such a dichotomously operating consciousness came from neuroimaging studies.

A study using fMRI found that activity in the anterior cingulate, medial prefrontal cortex and frontopolar cortex was linked to the conscious perception of targets during the attentional blink [22]. Del Cul et al. [16] reported activations in frontal, parietal and temporal cortex as a neural correlate of consciousness, with the prefrontal cortex being a necessary component [18], while participants performed the number categorisation task. The amplitude of the P3 component correlated with the subjective reports mentioned above, and thus showed a non-linear rise in accordance with the non-linear dynamics of the computational models [20,23]. In an other study using intracranial electroencephalogram recordings, participants categorised masked word stimuli as being threatening or non-threatening [24]. A series of analyses were performed on the intracranial EEG data and pointed consistently to the same conclusion: long-distance and sustained coherent activity more than 300 ms after stimulus presentation was associated with the conscious perception of the targets in the word categorisation task. All of these studies were interpreted in an in neural terms defined global workspace framework.

The Global Neural Workspace Theory (GNWT), originally inspired by the global workspace theory developed by Baars [25, 26], provides an encompassing model to frame all these results. The dichotomous or all-or-none nature of consciousness is caused by the absence or presence of ignition, the sudden moment at which parieto-frontal regions are active synchronously with posterior regions, thus generating a brain state during which stimuli become visible and available to report in various ways [23,27,28]. The essential components underlying dichotomy are thus global recurrent activation with non-linear neural dynamics.

Overall, it seems that paradigms that have involved tasks on number, letter or word stimuli have generally resulted in evidence for a dichotomous characterisation of consciousness, with non-linear psychophysical curves and all-or-none subjective judgments going hand in hand with non-linearly emerging recurrent activity on a global brain scale.

Gradedness or dichotomy?

To sum up, we appear to end up with a range of contradictory findings aimed at explaining a single phenomenon: visual awareness. The result is two opposing theoretical frameworks, one conceptualizing consciousness as graded, and one as dichotomous, the former proposing more graded and the latter more all-or-none underlying neural dynamics. However, when we look into the type of stimuli and tasks that have been used in these studies, we see a clear-cut and consequent difference between experiments supporting the graded or the dichotomous account. The use of basic visual stimuli such as orientation gratings and simple shapes resulted in evidence for the graded account or recurrent processing in and between posterior brain regions as a neural correlate of consciousness. The use of more elaborate stimuli like numbers or words resulted in evidence for the dichotomous account and a Global Neural Workspace framework. Additionally, it seems that also the measure to assess the subjectively experienced visibility has been different, as graded results stem mostly from PAS scale experiments, whereas dichotomous results are in essence obtained through the SDS scale (noting that on top of that different analyses have been proposed to show either gradedness or dichotomy, and that has been relied on mostly different behavioural markers: curves and accuracy comparisons for each subjective rating versus curves and subjective judgment distributions, respectively). In the next section we address the question of whether the consequent use of specific scales could have contributed to the controversy between the graded and the dichotomous accounts. We then outline a proposal for integration that addresses the potential confound that experimental tasks and stimuli have induced in previous work.

3. MORE DISCRETE AND MORE CONTINUOUS SCALES

Apart from stimulus and task-related issues, the characteristics of the subjective scales used in previous work might be another source of confound. We will focus our discussion on the scales that have been most frequently used to claim either gradedness or dichotomy. Evidence for the graded account has generally been collected on the basis of the PAS scale. As mentioned above, it consists of four individually labeled scale points, and could thus be called a “discrete” scale. On the other hand dichotomous evidence has usually been found through the SDS scale, which we could call a continuous scale. Participants dispose of 21 consecutive positions to indicate the clarity of their percept, and two labels indicate minimal and maximal visibility at the extreme ends of the scale. The question can be put forward whether these scale characteristics can drive participants into either graded or dichotomous response patterns, without necessarily reflecting their internal subjective states.

In the latter case, the presence of only two labels may make it difficult for participants to attach a perceptual strength to the 19 intermediate scale points. It could prove to be even too difficult to map 21 scale points to an equal number of mental states of clarity. This has been pointed out as well by Overgaard et al. [6] and Nieuwenhuis and de Kleijn [34]. Moreover, it is conceivable that moving a cursor with a continuous key press effort entails “ending up” at the extreme ends of the scale. It is striking to observe that time and again all-or-none distributions were observed using the SDS scale [16,18-20]. This can be either replicated evidence for the dichotomous account, or evidence for a scale bias. To our best knowledge, apart from a control experiment in the original study [19, but see next paragraph for a reinterpretation) only one study reported a relatively graded pattern in SDS data [35]. However, the experimental context was considerably different from the studies discussed here (i.e., implicit learning) and the distribution of the subjective SDS ratings was not examined as such but after division in four bins. Moreover there were still relatively little “2” and “3” ratings (i.e., the intermediate ratings of the four created bins) compared to “1” ratings and additionally, the average accuracy for ratings 2 and 3 was at about the same level but lower than the average accuracy for rating 1, which casts doubt on what perceptual states exactly corresponded to ratings 2 and 3. In any case, Sergent et al. [19] provide evidence themselves against the argument that an SDS bias would drive participants by definition into a bimodal pattern regardless their subjective perception.

In a backward masking experiment they showed how the SDS scale was used in a graded fashion [19]. On every trial, a number word or a blank was presented for six possible durations ranging from 14 up to 86 ms, followed by a mask. Participants didn’t have to do a discrimination or categorisation task, but immediately indicated their subjective visibility on an SDS scale. Results showed that for every stimulus duration a unimodal pattern was obtained: the Gaussian representing the frequency of each subjective rating was centered around an average that increased progressively for every longer stimulus presentation duration. This implies that intermediate ratings on the SDS scale are effectively used by the participants in a backward masking paradigm. In any case this seems to be convincing evidence that the SDS can behave in a graded fashion, providing evidence against the claim that it would be biased, while maintaining the support for a dichotomous character of consciousness, at least in their attentional blink task (but see the next section for a reinterpretation of these two experiments). We will now turn to the question whether a scale bias could be present in more discrete scales.

Indeed, all experiments that have used the PAS scale have found evidence for the graded account. Again, this can be convincing evidence for the graded account, at least with the low-level tasks used in these experiments, or it can be evidence for a PAS scale bias, driving participants into a graded pattern. It is intuitively imaginable that they feel obliged to use all four scale points, to justify the perceived demands of the experiment. Even if conditions of dichotomous visual experience exist, it might feel strange to them to use only ratings 1 and 4 during the whole experiment, whilst permanently seeing a scale with four points being proposed to them. The PAS scale has been developed to measure graded differences in visual perception, in order to avoid to force people into dichotomous reports [6]. The instructions to rate the personal visual experience and not the objective state of the stimulus on the screen allows for a “division of all possible subjective visual clarity states” onto four scale points, even for stimuli and tasks that are conceptually dichotomous such as numbers or words, as we will point out below. For example, if a word stimulus is briefly flashed on the screen, participants may very well choose rating 2 or 3 when they see half of the letters of the word, despite that we see a word as a whole entirely or entirely not (cf. section 4). Below we present a strategy to test this reasoning, together with evidence from recent experiments.

Recently, scale differences are acknowledged by some researchers who compared ratings across a set of scales. Sandberg et al. [4] compared the PAS scale to confidence ratings (CR) and wagering. As described in the introduction, masked geometrical shapes were presented for different durations and participants were required to identify the presented shape. Next to that, they indicated the visibility of the stimuli on the PAS-scale or they expressed their confidence in their identification performance (CR) on a four-point scale or they placed bets on their performance for four different amounts of money (wagering). Sigmoid curves were observed and especially for PAS, intermediate ratings were used. This led the authors to conclude that awareness is rather graded, but as we point out here, no different levels of processing were used, which makes it difficult to conclude whether there was a scale bias. This also applies to the more recent studies of Wierzchon et al. [35] and Szczepanowski et al. [36]. These studies are useful in order to examine the respective sensitivity of measures, but do not rule out scale biases. We argue that in order to rule out scale bias, stimulus or task features (level of processing) should be manipulated in order to compare gradedness or dichotomy for the same scale. This should be carried out for different scales in order to show these differences in the transition from unconscious to conscious perception for different levels of processing, independently of the scale at hand. If for example one scale consistently gives rise to graded patterns of results while several other scales indicate an all-or-none pattern, one could suspect a graded bias of the first scale.

Before we present a series of recent studies with the aim to verify whether such a scale bias for more discrete scales exists (more precisely a scale bias in the sense of that it produces consistently a graded or dichotomous pattern, regardless the subjective experience of the participants), we will outline our proposal for an integration due to a potential confound of level of processing on the graded or dichotomous nature of visual perception.

4. PROCESSING HIERARCHIES AND A PROPOSAL FOR INTEGRATION

If we look at the whole range of stimuli and tasks in the studies presented above, we go from experimental tasks using orientations over colours and shapes up to numbers and words. All these stimuli and tasks can be situated within a hierarchy. Hochstein and Ahissar [29] discuss hierarchies in the visual system. Successive cell types with progressively larger receptive fields along the dorsal and ventral pathway process increasingly complex stimuli. Brain regions along these pathways thus process basic visual features of stimuli such as orientations, colours and location at lower levels in the hierarchy, up to objects, abstract forms and categories at higher levels of processing. This way of reasoning stems mostly from the object categorisation literature [30,31], but has also been applied to written word recognition [32] and visual perceptual learning [33]. We propose that the debate between the graded and dichotomous account could equally benefit from taking the hierarchical level of processing of stimuli and tasks into account.

It appears that the use of stimuli and tasks that can be situated at a low level in the processing hierarchy versus at a high level maps consistently on graded versus dichotomous findings. Rather than being surprising, this seems to follow naturally if we analyse the nature of these stimuli. Colours for example, are inherently graded, consisting of three dimensions (red, green and blue). Our visual experience may therefore have many possible intermediate states of clarity. Low-level judgments will then reflect this gradedness. For high level stimuli this is conceptually different. If written words are presented briefly on a screen for different durations, only at a specific moment there is enough information in the system to know to which category a stimulus belongs (be it colour or word categories) or to integrate and perceive such multifeature stimuli entirely. In essence, perceiving a semantic stimulus conceptually entails seeing it or not seeing it (“seeing a letter is not seeing the word”). This could have brought about the dichotomous results.

We propose that precisely the level of processing of stimuli as induced by task requirements will determine whether stimulus awareness will be graded or dichotomous. Stimuli and tasks associated with lower hierarchical levels seem to be of a basic visual nature, unifeatural and conceptually graded, producing a graded visual experience. Stimuli and tasks associated with higher hierarchical levels tend to be of a semantic nature, multifeatural and conceptually all-or-none, resulting in a dichotomous visual experience. To our knowledge, no studies have controlled for level of processing within one experimental design, for example by explicitly contrasting stimuli or tasks associated with different levels of processing. In the next section we present a series of studies that aim to control for level of processing, thus attempting to reconcile the graded and the dichotomous account. Crucially, the same set of studies will address in parallel the potential confound of a scale bias.

5. EVIDENCE FOR GRADED AND DICHOTOMOUS AWARENESS

In this section we present a first wave of studies with the central aim of examining whether level of processing shapes our visual experience into a graded or a dichotomous one, by using stimuli and tasks at a different level of processing while assessing awareness with the same subjective scale. In parallel we want to verify whether the emerging pattern of results is informative on the presence of a scale bias in discrete scales, by using different versions of such scales.

In a first experiment we analysed psychophysical curves for two tasks at a different level of processing. We outlined above that studies showing evidence for the graded account were reporting gradually increasing psychophysical curves, whereas studies showing evidence for the dichotomous account reported steeply non-linear curves. Moreover, because for some studies those curves seemed to resemble each other visually, we explicitly wanted to contrast the curves for different levels of processing and examine whether we would observe two different psychophysical curve slopes, namely a gradual and a steeper curve. This would suggest that level of processing may be a relevant factor in the graded and dichotomous debate. We developed a paradigm where participants expressed either low-level or high-level judgments on the very same stimuli [37]. On every trial throughout the experiment a coloured digit was briefly presented on the center of the screen, preceded and followed by a square pattern mask. Stimulus durations ranged from 10 over 20, 30, and so on up to 80 ms. Task requirements were manipulated within subjects. During one half of the experiment, participants performed a low-level categorisation task, indicating whether the colour of the coloured digit was red or blue. During the other half, task instructions required a high-level semantic categorisation. There, the task was to judge whether the number value of the coloured digit was smaller or larger than five. Importantly, participants attached a value to the subjectively perceived clarity through the PAS scale, equally on every trial. We then compared the psychophysical curves of the low-level and the high-level tasks. To this end we fitted non-linear regression models to the curves (see above, and 5). The crucial parameter here was the *d* parameter. As lower *d* values indicate a steeper non-linearity, we predicted to find a significantly lower *d* value in the high-level condition than in the low-level condition. This was effectively the case for both task performance and subjective reports. Importantly, there

Figure 1 about here

was no difference in accuracy or subjective visibility when all durations were averaged. These results imply that the psychophysical curve was significantly more non-linear in the high-level than in the low-level task, mirroring the results of previous psychophysical work. Level of processing modulated the accuracy and subjective visibility as expected based on previous conflicting evidence, suggesting that level of processing may be important in reconciling the graded and the dichotomous account. Showing an influence of level of processing on the steepness of the psychophysical curves was important to explicitly show within one design, using exactly the same stimuli, that we could obtain patterns previously consistently associated with either the graded or the dichotomous view. However, as we also pointed out in the discussion of these data, curves cannot be used to directly claim graded or dichotomous visual experience as such. For example, even if participants would only use 1 and 4 PAS ratings throughout the whole experiment – which would indicate an all-or-none experience – we could still observe a gradually increasing psychophysical curve (e.g., if participants use progressively use more 4 ratings for every higher stimulus duration). Even though gradually (non-linearly) increasing curves were consistently associated with evidence for the graded (dichotomous) account, we turn to the distribution of subjective judgments as a direct marker for the nature of visual experience.

In Sergent et al. [19], the distribution of subjective ratings was compared for two different tasks: an attentional blink and a masking paradigm. In the former, as explained above, participants needed to rate the subjective clarity of a four-letter number word (the second target, T2 in attentional blink terminology), which had to be detected among a stream of rapidly presented four-letter consonant strings. Additionally, on two thirds of the trials participants had to report whether the two central letters of the first target in the stream (cf. T1) were "OO" or "XX". The results of the subjective ratings on T2 showed that a bimodal distribution was observed, which was interpreted as evidence for a dichotomous character of consciousness. In their masking experiment, which was carried out to show that the SDS scale could also behave in a graded fashion, participants rated their subjective clarity simply after looking at a masked number word. While it is true that words were used as stimuli in both the attentional blink and the masking task in Sergent et al., there are some considerable differences in the extent to which the stimuli are processed, because of the demands of the particular task. In the attentional blink task, number words are presented among a series of consonant strings in a high-paced fashion. In order to make any sort of judgment related to the number words, they need to be able to discriminate the word from the consonant strings, which implies a strong semantic component. Trials in the masking task are very different, as well as the associated task demands. The semantic task component from the attentional blink task is not present in the masking task. Participants can merely report the low-level clarity of the word, i.e., to what extent did they see something appearing on the screen. There was no categorisation task on the masked words preceding subjective judgments for example, which could have induced semantic processing, in contrast with our own experiment reported above. While we cannot exclude on the basis of their data that stimuli were semantically processed during the masking task, the task demands of the masking and attentional blink tasks in Sergent et al. appear to induce low-level and high-level processing, respectively. In that case, on top of providing evidence against an all-or-none SDS scale bias, they also provided evidence for our claim that low-level non-semantic tasks are associated with graded visual experience, whereas high-level semantic processing leads to dichotomous awareness. Note that this interpretation is very different from theirs, which maintains the position that consciousness is dichotomous, even though a part of the results indicate otherwise (this latter point has also been made by 6). We then reanalysed our "coloured number" experiment to see whether we could observe such a modulation of the subjective PAS judgments when comparing the low-level with the high-level task within the same experiment.

For the PAS scale we can compare the frequency of each rating between the low-level and high-level condition. Predicting gradedness in the low-level task, we would expect that all scale points are used. Conversely, we would expect frequent (if not exclusive) use of the "extreme" scale points 1 and 4 in the high-level task, and no or almost no use of the intermediate scale points. However, we observed that in both the colour and the number task

Figure 2 about here

all scale points were used. This could imply that either our hypothesis on the influence of level of processing was falsified, or that participants failed to react with regard to the stimuli as a whole. As we reasoned above it may be very well possible that participants use all PAS scale points simply because of wanting to satisfy the assumed demands of the experiment, rating subjective clarity in a graded fashion rather based on the extent to which they see elements of the coloured numbers, despite the conceptual all-or-none nature of seeing a semantic multi-featural number stimulus either entirely or entirely not. In a few pilot experiments for other studies we kept observing that participants used all PAS scale points. An interesting way to get around the problem of disentangling gradedness or dichotomy from such potentially biased scale result patterns, could be to compare the different subjective ratings to an other variable, such as accuracy (cf. 3, 4, 6, 35).

It is not straightforward to distinguish gradedness from dichotomy if we suspect that demand characteristics influence the way in which subjective judgments are given. As we pointed out above, one strategy to detect a possible bias of discrete scales towards gradedness could consist of comparing the pattern of results produced by the same scale in different paradigms. More specifically, comparing the accuracy on the categorisation task for each subjective rating could be a solution. Interestingly, it will become clear that one experimental design will make it possible to test the influence of level as processing as well as a potential scale bias for discrete scales. In a recent study we carried out, we tested 14 participants in a design from which the logic is comparable to the colour-number paradigm. In this experiment we present coloured words on half of the trials, which are premasked and postmasked with hashes and percent symbols. In the other half of the trials there is only a blank between the masks. Importantly, there is only one presentation duration of 50 ms,

Figure 3 about here

so on every trial the objective stimulus strength is identical. Therefore, the way in which stimuli are presented does not contain an inherent graded component, unlike in psychophysical designs with multiple durations. During one half of the experiment, the task is to indicate whether the word was written in red or blue (i.e., a low-level basic visual task). During the other half of the experiment, the task is to judge whether the word was an animal or an object (i.e., a high-level semantic task). Participants were also given a discrete scale with three scale points as in Christensen et al. [7] (see Figure 3 for the trial sequence and an English version of the discrete scale with three points). Indeed, in Sandberg et al. [5], a comparison between a 3 and a 4 point PAS scale revealed that the accuracy for the fourth point was the same as for the third point of both variants, and thus appeared to give no additional information. It was indicated that the scale ranged from "I haven't identified the stimulus in its entirety" to "I have identified the stimulus in its entirety". By emphasizing that reports pertained to the stimulus in its entirety, we wanted to stimulate subjective judgments to report the extent of experience of stimuli as a whole. Therefore, conceptually, we do not expect a lot of 2 ratings in the high-level task if participants followed the instruction to rate their identification of the word as a whole. Either they saw the word entirely (rating 3) or they didn't saw the word entirely (rating 1). Conversely, in the low-level colour task, it is conceptually conceivable to perceive and report the colour clarity with three different ratings on this scale. However, this difference between tasks is not what we observe. Participants keep using all scale points in both the low-level and high-level task (interaction between level of processing and scale point on frequency of scale point use, $F < 1$). This is not because participants use

Figure 4 about here

the scale points randomly: on target-absent trials participants make almost exclusive use of rating 1. But then, if accuracy is taken into account, a very different pattern emerges from the graded ratings in both tasks. We conducted a 2 x 3 repeated measures analysis on Accuracy with Level of Processing (low-level vs. high-level) and Scale point (1 vs. 2 vs. 3) as factors. The interaction between Level of processing and Scale point on Accuracy was significant ($F(2,12) = 4.571$, $p < 0.05$), indicating that the evolution of accuracy over scale points was different in the low-level versus the high-level task. This difference between accuracy patterns between the two tasks despite identical graded use of the discrete scale over tasks could moreover indicate a possible scale bias for discrete scales towards gradedness. For the low-level colour task, differences in accuracy were very subtle, rising gradually from one subjective scale point to another. The accuracy difference between rating 1 and 2 was not significant ($t(13) = 1.282$; $p = 0.111$); as well as the difference between rating 2 and 3 ($t(13) = 0.485$, $p = 0.318$), while the difference between rating 1 and 3 was marginally significant ($t(13) = 1.635$; $p = 0.063$). For the high-level semantic task, participants performed at chance level when they indicated no stimulus identification, and around 90% accurate when ratings 2 are 3 were given. The accuracy difference between rating 1 and 2 was significant ($t(13) = 4.719$; $p < 0.0001$), while the difference between rating 2 and 3 was not significant ($t(13) = 0.622$; $p = 0.544$). These differences in frequency of subjective ratings (perhaps due to fluctuations in

Figure 5 about here

pre-stimulus attention) and differences between tasks are spectacular if taken into account that on every trial, stimulus strength is identical and the variability in perceptual clarity is entirely subjective. Despite stimulus presentation that does not contain a graded component and a conceptual difference between level of processing as induced by the task, a graded way of scale use is observed. But despite this graded pattern in both tasks and no variability in stimulation, very different underlying accuracy patterns are observed. It appears that participants can map a graded experience of colour onto three different subjective scale points in the low-level task. Conversely, there are only two states of accuracy in the high-level task: on chance performance and nearly perfect performance. These two states of stimulus identification were mapped onto three different scale points in this experiment, perhaps to satisfy perceived demands of the experiment when such a scale is proposed. Even when the scale is adapted to accommodate stimulus perception “as a whole”, all scale points of a more discrete scale tend to be used regardless level of processing or the nature of the stimulus or task.

As for the bigger picture, evidence starts to emerge that level of processing plays an important role in whether our visual experience of a stimulus during task execution will be graded or dichotomous. The data suggest that low-level processing of basic visual stimuli results in a graded experience, and high-level processing of semantic nature results in a dichotomous experience. Moreover, different versions of discrete subjective scales result generally in a graded pattern of results, even when underlying accuracy patterns suggest otherwise. In the next section we compare these findings with other studies and theories in the literature, and we formulate proposals for further research.

6. CONCLUDING DISCUSSION

Our findings that level of processing modulates whether our visual experience of the world is graded or dichotomous offers a parsimonious integration of the contradictory findings presented in the introduction. When participants were asked to process low-level non-semantic content, we observed (1) gradually increasing psychophysical curves, (2) subjective reports of intermediate awareness states and (3) a gradual increase in performance from lower to higher subjective degrees of visibility. In contrast, when participants were asked to process high-level semantic content involving multiple features, we observed (1) more steeply increasing psychophysical curves around threshold, (2) an all-or-none use of the subjective scale (in some cases), and (3) an all-or-none pattern of performance even when participants also used intermediate scale points. The latter result suggests a scale bias that induced the use of all scale points irrespective of the actual subjective states of the participant. Theoretically, our data support our perspective — the idea that the disparate results observed in the literature concerning the graded vs. dichotomous nature of visual perception can in fact be integrated.

Importantly, our suggested integration is different from the one proposed by the partial awareness hypothesis [38]. According to the partial awareness hypothesis, the graded nature of consciousness stems from the involvement of multiple hierarchical representational levels each accessed in a dichotomous manner. Intermediate states in visual experience are thus best seen as consisting of full (all-or-none) awareness of certain stimulus features (e.g., a single letter in a word) with the remaining stimulus features simply failing to have been processed to the extent that they could have been "broadcasted" in the global workspace. An important implication of this hypothesis is that stimuli consisting of a single feature should be accessed in a dichotomous manner. However, in our studies, the low-level (e.g., colour) content nevertheless resulted in graded visual awareness, suggesting a genuine differential access pattern for different hierarchical representational levels. The partial awareness hypothesis therefore appears to be better suited to explain the nature of awareness of high-level stimuli with inherent different levels of semantic content (e.g., words) than for stimuli that essentially consist of a single graded feature. Of course, as we mentioned in the discussion, any motor or verbal report about a stimulus will tend to involve a semantic all-or-none decision. However, we showed that the subjective experience that leads to the report was graded for low-level content in our studies (as in the literature), a fact that becomes apparent when we look not only at single responses but at their entire distribution over a series of trials (for example when participants regularly use intermediate scale points).

What would then be the best method to establish that visual awareness is graded or dichotomous? As is evident from our experiments, the nature of awareness should not be determined based exclusively on one type of stimulus, task or scale. Here, we showed that we have to take into account the level of processing that specific stimuli and tasks involve. As for subjective scales, we argue that every such scale will reflect in some way the degree of visibility exhibited by the participants, which renders them all useful measuring instruments. However, due to potential scale biases, it is less straightforward to be conclusive on gradedness vs. dichotomy when examining the data produced by each scale separately. We therefore want to advocate our approach to not only compare different levels of processing within a single experiment, but to also carry out several such experiments using different scales (with different instructions, different numbers of scale points, different numbers of labels describing the scale points, etc.). Analyzing the overall pattern that emerges warrants a more reliable conclusion about gradedness vs. dichotomy. For now, the pattern that arises appears to be that low-level processing of non-semantic stimuli consisting of single features is associated with a graded visual experience, whereas high-level processing of semantic stimuli consisting of multiple features is associated with dichotomous visual awareness. More research is of course necessary to confirm modulation by level of processing (as well as potential scale biases of subjective visibility scales used in the experiments).

A potentially fruitful next step would be to manipulate level of processing also in neuroimaging studies. Based on the neuroimaging work presented in the introduction, we would predict to observe more local posterior recurrent processing for low-level stimuli and tasks as a neural correlate of consciousness. During high-level processing, in contrast, we would expect a global neuronal workspace (fronto-parieto-temporal activation) with non-linear neural activity patterns to correlate with subjective experience. Despite contradictory predictions, both the recurrent processing hypothesis [15] and the GNWT [27] rely heavily on recurrent processing. Both theories are thus as such prone to reconciliation, and an integration would be relevant at both an empirical as well as a theoretical level.

Interestingly, Koivisto and Revonsuo [39] and Koivisto and Silvanto [40] recently made a very similar proposal. According to their theory, phenomenal experience of features is generated through local recurrent processing, but awareness of stimuli after feature binding demands recurrent processing, modulated by attention and taking place at a later processing stage than the initial phenomenological experience. The authors map this difference onto the distinction between P and A consciousness [41]. In the context of our own experiments however, we need to be careful when assuming that our low-level conditions involve P-consciousness. Indeed, participants are still producing a report on the colour stimuli, whereas P-consciousness, according to the distinction made by Block [41] is assumed to go precisely beyond what is reportable. In this respect, the perceptual task in Goldberg, Harel and Malach [42] is interesting. In their data at least, they could not find any frontal contribution to passive viewing of visual stimuli. For now it is thus more careful to state that our integrative approach primarily concerns A consciousness and involves a difference in access to low-level and high-level stimuli. More studies are clearly needed to address the associations and dissociations between level of processing, feature integration, the range of recurrent processing, and the distinction between P and A consciousness.

To summarise, we suggest that level of processing modulates visual awareness. We propose to include low and high-level tasks in the same experimental designs, while comparing a series of subjective visibility scales. The benefit is an empirical and theoretical integration of findings and frameworks which have been previously taken to be contradictory. In short we can conclude that what we see determines how we see it.

Acknowledgements

B.W., A.V. and A.A. are supported by a fellowship from the National Fund for Scientific Research (FRS – FNRS Belgium). A.C. is a Research Director with the same institution. This research was partially funded by F.R.S.-FNRS grant "Conscious and Unconscious Processing" and by IAP grant P7/33 funded by the Belgian Science Policy Office.

References

1. Goldfield, B. A. & Reznick, J. S. 1990 Early lexical acquisition: rate, content, and the vocabulary spurt. *J. Child Lang.* **17**, 171-183.

2. Barth, H. C., Paladino, A.M. 2010 The development of numerical estimation: evidence against a representational shift. *Developmental Sci*. **14**, 125-135.

3. Overgaard, M., Feldbæk Nielsen, J., Fuglsang-Frederiksen, A. 2004 A TMS study of the ventral projections from V1 with implications for the finding of neural correlates of consciousness. *Brain Cognition* **54**, 58-64.

4. Sandberg, K., Timmermans, B., Overgaard, M., Cleeremans, A. 2010 Measuring consciousness: Is one measure better than the other? *Conscious. Cogn*. **19**, 1069-1078.

5. Sandberg, K., Bibby, B.M., Timmermans, B., Cleeremans, A., Overgaard, M. 2011 Measuring consciousness: Task accuracy and awareness as sigmoid functions of stimulus duration. *Conscious. Cogn*. **20**, 1659-1675.

6. Overgaard, M., Rote, J., Mouridsen, K., Ramsøy, T. 2006 Is conscious perception gradual or dichotomous? A comparison of report methodologies during a visual task. *Conscious. Cogn*. **15**, 700-708.

7. Christensen, M., Ramsøy, T., Lund, T., Madsen, K., Rowe, J. 2006 An fMRI study of the neural correlates of graded visual perception. *NeuroImage* **31**, 1711-1725.

8. Ro, T., Breitmeyer, B., Burton, P., Singhal, N., Lane, D. 2003 Feedback contributions to visual awareness in human occipital cortex. *Curr. Biol*. **13**, 1038-1041.

9. Silvanto, J. 2005 Double Dissociation of V1 and V5/MT activity in Visual Awareness. *Cereb. Cortex* **15**, 1736-1741.

10. Pascual-Leone, A., Walsh, V. 2001 Fast backprojections from the motion to the primary visual area necessary for visual awareness. *Science* **292**, 510-512.

11. Boehler, C., Schoenfeld, M., Heinze, H., Hopf, J. 2008 Rapid recurrent processing gates awareness in primary visual cortex. *P. Natl. Acad. Sci. USA*. **105**, 8742-8747.

12. Fahrenfort, J. J., Scholte, H.S., Lamme, V. A. F. 2007 Masking disrupts reentrant processing in human visual cortex. *J. Cognitive Neurosci.* **19**, 1488-1497.

13. Fahrenfort, J. J., Scholte, H.S., Lamme, V. A. F. 2008 The spatiotemporal profile of cortical processing leading up to visual perception. *J. Vision* **8**, 12.

14. Lamme V. A. F. 2006 Towards a true neural stance on consciousness. *Trends Cogn. Sci*. **10**, 494-501.

15. Lamme V. A. F. 2010 How neuroscience will change our view on consciousness. *Cognitive Neuroscience* **1**, 204-220.

16. del Cul, A., Baillet, S., Dehaene, S. 2007 Brain dynamics underlying the nonlinear threshold for access to consciousness. *PLoS Biol*. **5**, e260.

17. del Cul, A., Dehaene, S., Leboyer, M. 2006 Preserved subliminal processing and impaired conscious access in schizophrenia. *Arch. Gen. Psychiat*. **63**, 1313-1323.

18. del Cul, A., Dehaene, S., Reyes, P., Bravo, E., Slachevsky, A. 2009 Causal role of prefrontal cortex in the threshold for access to consciousness. *Brain* **132**, 2531-2540.

19. Sergent, C., Dehaene, S. 2004 Is Consciousness a Gradual Phenomenon? *Psychol. Sci.* **15**, 720-728.

20. Dehaene, S., Sergent, C., Changeux, J. 2003 A neuronal network model linking subjective reports and objective physiological data during conscious perception. *P. Natl. Acad. Sci. USA.* **100**, 8520-8525.

21. Dehaene, S., Kerszberg, M., Changeux, J. 1998 A neuronal model of a global workspace in effortful cognitive tasks. *P. Natl. Acad. Sci. USA*. **929**, 152-165.

22. Feinstein, J., Stein, M., Castillo, G., Paulus, M. 2004 From sensory processes to conscious perception. *Conscious. Cogn.* **13**, 323-335.

23. Dehaene, S., Changeux, J. 2005 Ongoing Spontaneous Activity Controls Access to Consciousness: A Neuronal Model for Inattentional Blindness. *PLoS Biol*. **3**, e141.

24. Gaillard, R., Dehaene, S., Adam, C., Clémenceau, S., Hasboun, D., Baulac, M., et al. 2009 Converging Intracranial Markers of Conscious Access. *PLoS Biol.* **7**, e61.

25. Baars, B. J. *A cognitive theory of consciousness*. Cambridge University Press. 1988.

26. Baars, B. J. 2002 The conscious access hypothesis: origins and recent evidence. *Trends Cogn. Sci*. **6**, 47-52.

27. Dehaene, S., Changeux, J., Naccache, L., Sackur, J., Sergent, C. 2006 Conscious, preconscious, and subliminal processing: a testable taxonomy. *Trends Cogn. Sci*. **10**, 204-211.

28. Dehaene, S., Changeux, J. 2011 Experimental and Theoretical Approaches to Conscious Processing. *Neuron* **70**, 200-227.

29. Hochstein, S., Ahissar, M. 2002 View from the top: Hierarchies and Reverse Hierarchies in the visual system. *Neuron* **36**, 791-804.

30. Malach, R., Levy, I., Hasson, U. 2002 The topography of high-order human object areas. *Trends Cogn. Sci*. **6**, 176-184.

31. Riesenhuber, M., Poggio, T. 1999 Hierarchical models of object recognition in cortex. *Nat. Neurosci.* **2**, 1019-1025.

32. Dehaene, S., Cohen, L., Sigman, M., Vinckier, F. 2005 The neural code for written words: a proposal. *Trends Cogn. Sci*. **9**, 335-341.

33. Ahissar, M., Hochstein, S. 2004 The reverse hierarchy theory of visual perceptual learning. *Trends Cogn. Sci*. **8**, 457-464.

34. Nieuwenhuis, S., de Kleijn, R. 2011 Consciousness of targets during the attentional blink: a gradual or all-or-none dimension? *Attent. Percept. Psycho*. **73**, 364-373.

35. Wierzchoń, M., Asanowicz, D., Paulewicz, B., Cleeremans, A. 2012 Subjective measures of consciousness in artificial grammar learning task. *Conscious. Cogn*. **21**, 1141-1153.

36. Szczepanowski, R., Traczyk, J., Wierzchon, M., Cleeremans, A. 2013 The perception of visual emotion: Comparing different measures of awareness. *Conscious. Cogn*. **22**, 212-220.

37. Windey, B., Gevers, W., Cleeremans, A. 2013 Subjective visibility depends on level of processing. *Cognition* **129**, 404-409.

38. Kouider, S., de Gardelle, V., Sackur, J., Dupoux, E. 2010 How rich is consciousness? The partial awareness hypothesis. *Trends Cogn. Sci*. **14**, 301-307.

39. Koivisto, M., Revonsuo, A. 2010 Event-related brain potential correlates of visual awareness. *Neurosci. Biobehav. R*. **34**, 922-934.

40. Koivisto, M., Silvanto, J. 2011 Relationship between visual binding, reentry and awareness. *Conscious. Cogn*. **20**, 1293-1303.

41. Block N. 2007 Consciousness, accessibility, and the mesh between psychology and neuroscience. *Behav. Brain Sci.* **30**, 481-499.

42. Goldberg, I. I., Harel, M., Malach, R. 2006 When the brain loses its self: Prefrontal Inactivation during Sensorimotor Processing. *Neuron* **50**, 329-339.

Figures

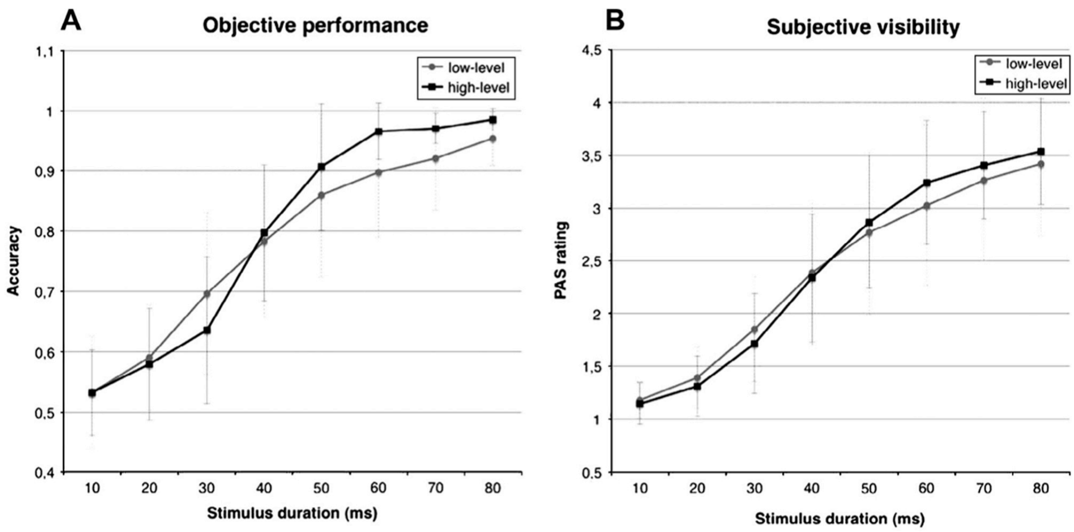

Figure 1: Psychophysical curves computed for the objective task performance data and the subjective visibility data. We observe significantly more non-linear curves in the high-level condition than in the low-level condition for both dependant variables.

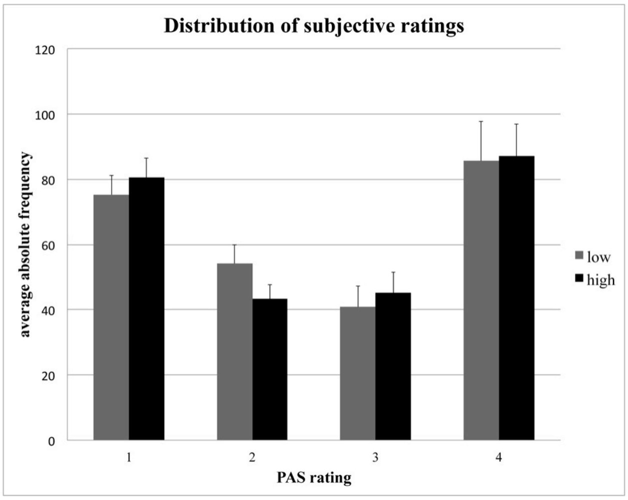

Figure 2: Distributions of subjective ratings for the low-level and high-level condition. For every PAS rating the average frequency over participants is shown. In both conditions, intermediate ratings 2 and 3 are used for about one third of the trials.

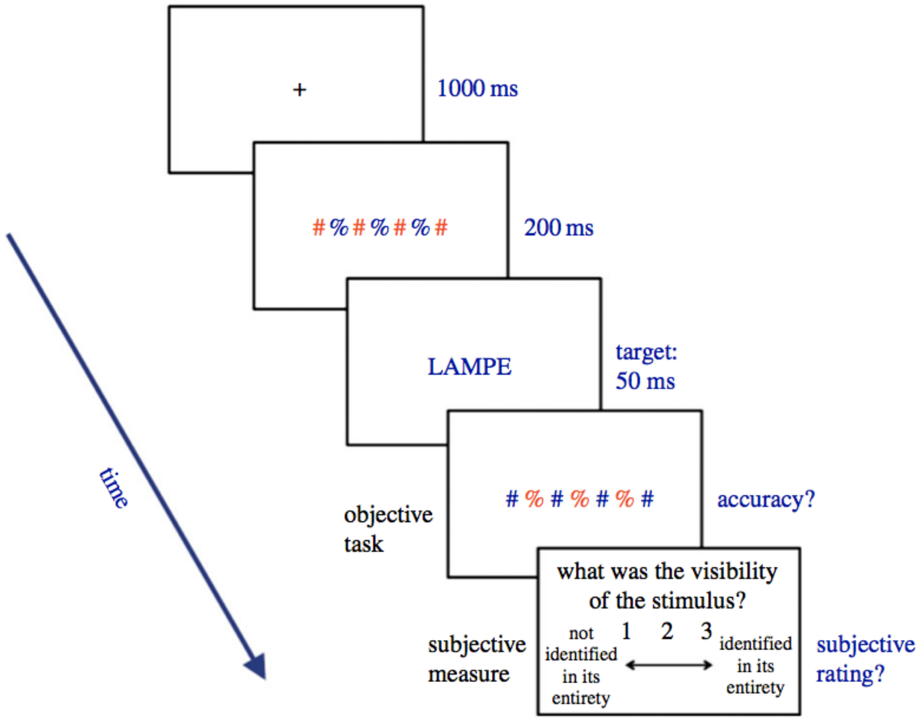

Figure 3: Trial procedure. A fixation cross is followed by a sandwich-masked coloured word that is either an animal or an object. Participants press G or H, respectively. Then, they indicate their subjective visibility with a keypress on 1, 2 or 3 on the numerical pad of the keyboard.

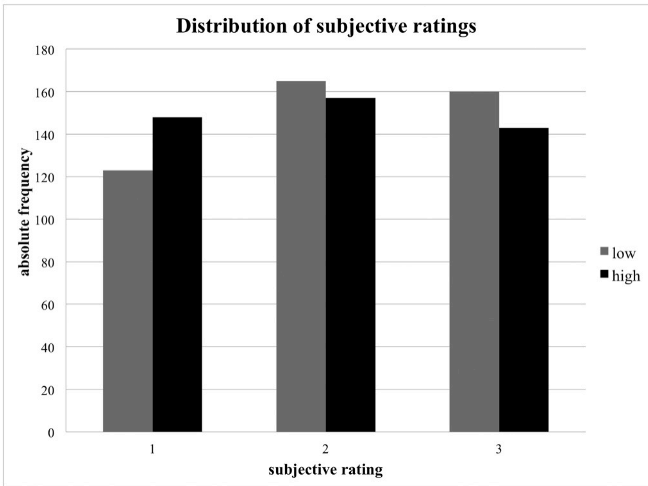

Figure 4: Distributions of subjective ratings for the low-level and high-level condition. In both conditions, participants use all three scale points, including the intermediate step.

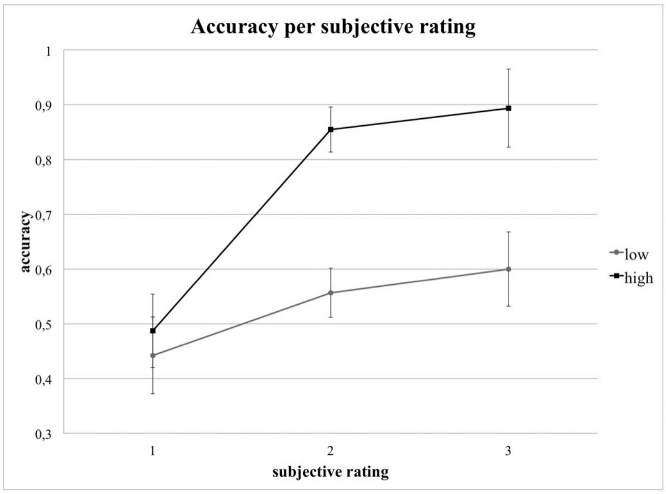

Figure 5: Average accuracy for each subjective rating. Performance increases gradually for each scale point in the low-level task. In the high-level task, participants perform either on chance level, or are correct (i.e., ceiling performance).