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Visual expectations change subjective experience without changing performance

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ABSTRACT

It is widely believed that visual expectations can change the subjective experiences of humans. We investigated how visual expectations in a recognition task affected objective performance and subjective perception. Using a 2-alternative-forced-choice task based on digit recognition of briefly presented and visually masked digits, we found over two experiments that expectations changed the quality of the experiences without changing the performance capabilities associated with the quality of experience. Expectations were manipulated by providing a cue indicating the set of possible digits that might appear on each trial.

The results also inform the debate about whether subjective experiences can be categorized in a dichotomous manner or in a graded manner. We found that subjective experiences were graded near the objective threshold and more dichotomous away from the threshold. Furthermore, distinct expectations resulted in a more dichotomous distribution of subjective experience.

We also provide evidence of an interesting relationship between stimulus duration, objective performance and subjective ratings. Only experiences that were rated as evoking some degree of perception showed systematic improvements in objective performance as a function of stimulus duration.

These findings suggest that subjective experience cannot be understood without considering the broader cognitive context, namely that the quality of subjective experiences is dependent on a multitude of factors such as attention, task requirements and cognitive expectations.

1. Introduction

Human beings subjectively experience a rich visual world full of different objects. Looking at a visual scene, such as a cat on a mat, one will under normal circumstances be visually conscious of that cat on that mat. A simple way to eliminate conscious visual content of the cat on the mat is to close one's eyes. From this simple example, it is natural to assume that subjective experiences fall into one of two dichotomous states; either one is subjectively experiencing a visual object or one is not. However, there might be states that fall between conscious and unconscious. An everyday example of this is seeing something in the periphery of one's visual field. One may have a vague perception of something, but the object is not seen as clearly or vividly as something in central vision; thus, it seems that the concept of being conscious can be graded in terms of the vividness of one's experience.

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To investigate how finely nuanced subjective experiences can be, one can use subjective scales to let participants rate the clarity of their experiences. For example, Sergent and Dehaene (2004) argued, based on an attentional blink task, that perceptual consciousness is bimodal, and that subjective experiences are dichotomous such that a stimulus is either “seen” or “not seen”. The attentional blink (Raymond, Shapiro, & Arnell, 1992) is a phenomenon that occurs when two target stimuli, T1 and T2, are presented briefly among a series of rapidly presented distractors (Raymond et al., 1992). As long as one is only required to respond to one of the targets, one almost never misses that target. When responses are required for both targets, however, T2 is often reported as failing to evoke any subjective experience, presumably due to attention being directed towards T1. These findings led Sergent and Dehaene (2004) to conclude that subjective experiences occur in an all-or-none manner, rather than along a graded continuum. An important consideration, however, is that of how many points should be used for the subjective rating scale. This is not a trivial concern since the number of points and the descriptions associated with them may influence how participants rate their perceptions. Sergent and Dehaene (2004) used a 21-point scale with 0% and 100% visibility at each end and steps of 5% in between. Nieuwenhuis and de Kleijn (2011) performed an experiment similar to that of Sergent & Dehaene, but had participants use a 7-point scale to rate perceptual consciousness. The rationale for reducing the number of scale points was based on the arguments of Overgaard, Rote, Mouridsen, and Ramsøy (2006) that participants are unlikely to be able to meaningfully categorize their experiences into 21 discrete ratings. Using a reduced number of scale points, they found compelling evidence of a more graded distribution of subjective experience ratings than Sergent & Dehaene did. They also tested how the task influenced ratings of subjective experience. When the task on T1 was made more difficult, requiring participants to indicate which of 8 different digits was shown, the ratings on the 7-point scale were distributed in an even more graded fashion, where all scale points were used. The gradedness of subjective ratings of perceptual consciousness thus seems to depend on both the rating scale used and the difficulty of the task, and the latter may depend in part on the number of potential targets to be discriminated. Introducing more targets, however, does not *only* change task difficulty, but it also alters the expectations that the observer has towards the stimuli. In effect, multiple attentional or recognition templates may be activated or primed in an experiment that requires identifying which of many possible targets are presented on each trial.

Expectations regarding what one is likely to see can also shape one’s conscious experience (Kok, Brouwer, Gerven, & Lange, 2013; Pearson, Rademaker, & Tong, 2011; Pinto, van Gaal, de Lange, Lamme, & Seth, 2015; Summerfield & Egner, 2009; Aru, Tulver, & Bachmann, 2018). Being on a football field may cause one to perceive a round object in the visual periphery as a football, whereas being on a baseball field may cause one to perceive it as a baseball, even if the sensory stimulation is identical. Other sensory modalities may of course also be associated with differences in consciousness and expectations, but for this study, we will use the term “subjective experience” to refer to visual experiences only.

In the present study, we investigated how differences in expectations, in and of themselves, may influence ratings of subjective experience. We expected that less distinct expectations would result in more graded perception. What this means will be considered in greater detail below.

We used the Perceptual Awareness Scale (PAS: Ramsøy & Overgaard, 2004), which has 4 categorically different ratings: No Experience (NE), Weak Glimpse (WG), Almost Clear Experience (ACE) and Clear Experience (CE) (Table 1).

The PAS scale (Sandberg & Overgaard, 2015; Sandberg, Timmermans, Overgaard, & Cleeremans, 2010) has been shown to provide better fits to participant performance in terms of being more *exhaustive* and *sensitive* than both confidence ratings and post-decision wagering (Koch & Preuschoff, 2007) and also to provide better fits than dichotomous scales (Overgaard et al., 2006). For a scale to be exhaustive, the scale must provide evidence that when participants claim to have no experience and no knowledge about what was shown (Table 1: No Experience), their performance should not be different from chance-level performance. For a scale to be sensitive, the scale must provide points such that when participants claim to have some degree of experience and knowledge (Table 1: Weak Glimpse, Almost Clear Experience and Clear Experience), their performance should correlate with the clarity of the experience and amount of knowledge reported. This means that whatever difference participants claim to feel should be reflected by a real difference in objective performance.

Here we test the cognitive manipulation of expectations that participants have towards prospective stimuli. We also test the impact of stimulation manipulation by varying stimulus duration. The primary goal of this study was to assess whether the distinctness of one’s expectations towards prospective stimuli influences how clearly they are experienced. A secondary goal was to assess whether PAS is an exhaustive scale. With respect to the primary goal, we expected that more distinct expectations would result in clearer subjective experiences. Specifically, we predicted that less distinct expectations should lead to more frequent reports of Weak Glimpses and Almost Clear Experiences (Table 1), and less frequent reports of Clear Experiences. For the secondary goal, evidence that cognitive or stimulation manipulations can enable above-chance performance would be evidence against PAS being an exhaustive scale. In

Table 1
The Perceptual Awareness Scale (PAS).

Label	Description (from: Ramsøy & Overgaard, 2004)
(1) No Experience (NE)	No impression of the stimulus. All answers are seen as mere guesses
(2) Weak Glimpse (WG)	A feeling that something has been shown. Not characterized by any content, and this cannot be specified any further
(3) Almost Clear Experience (ACE)	Ambiguous experience of the stimulus. Some stimulus aspects are experienced more vividly than others. A feeling of almost being certain about one’s answer
(4) Clear Experience (CE)	Non-ambiguous experience of the stimulus. No doubt in one’s answer

Note: Scale steps and their descriptions.

operationalized terms, if PAS is not exhaustive, we should observe that the manipulation of expectations and/or of stimulation should enable above-chance performance. We operationalized the distinctness of expectations by presenting cues to participants about upcoming stimuli. Cues would indicate that stimuli would either come from a set of two, four or eight stimuli as described in the methods below. We conducted two experiments since the evidence from Experiment 1 was ambiguous towards whether the distinctness of expectations affected conscious experience, because of a potential confound of differing levels of accuracy. Experiment 2 removed this ambiguity.

2. Experiment 1

2.1. Material and methods

2.1.1. Participants

29 participants, 18 women and 11 men, with normal or corrected-to-normal vision, provided informed written consent, and the study took place under the approval of the Institutional Review Board of Vanderbilt University. No formal power calculations were done, but the sample size was chosen to be twice the size of the experiments (Nieuwenhuis & de Kleijn, 2011; Sergent & Dehaene, 2004) central to this study. Six participants were excluded from the analyses: two due to instability issues of the experimental programme, two due to failing to use the full range of possible subjective reports and finally, two due to shifts in their criterion in the midst of the experiment. In the latter case, both participants only started using the Clear Experience rating about halfway into the experiment.

2.1.2. Stimuli and procedure

Participants were seated 45 cm from a CRT-monitor running with a resolution of 1024 × 768 pixels and a refresh rate of 85 Hz. Target stimuli consisted of Arabic numerals ranging from 2 to 9, presented using the "digital-k" font (Fig. 1) (http://gnome-look.org/content/show.php/DigiTalk-mono+%5Bdigital+clock+font%5D?content=132902, [date last accessed: 30 October 2018]). Participants were instructed to report the parity of the target stimulus, that is, whether the target digit was even or odd. Task difficulty was manipulated by varying the interstimulus interval between the target digit and the subsequent visual mask. The parity task was chosen so that the discrimination task remained a 2-alternative-forced-choice (2AFC) task while the number of potential targets could be varied.

Each trial (Fig. 1) began with a white cue (115 cd/m^2) presented on a grey background (31.0 cd/m^2), indicating the set of digits from which the target digit would be randomly drawn from on that trial. This cue was always valid and always consisted of an equal amount of even and odd digits. The number of possible targets that were cued consisted of either 2, 4, or 8 digits. The cues were

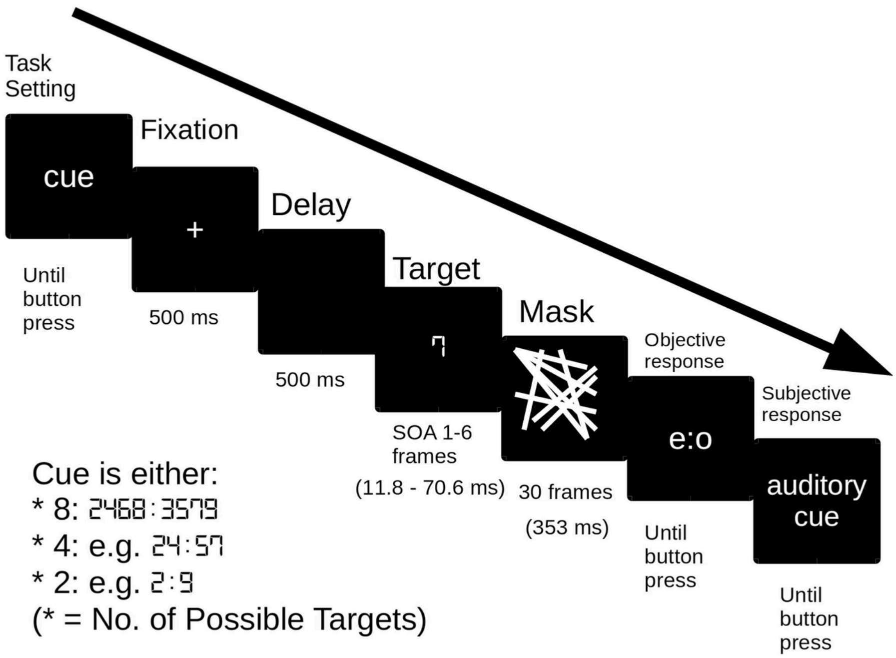

Fig. 1. Experimental paradigm. A cue was presented, creating a top-down expectation as to which digits could be presented. The Number of Possible Targets was one of 3 levels (2, 4 or 8 alternatives). A cue was repeated for 12 trials and was then changed. A high-pitched sound alerted participants whenever the cue changed. A fixation cross (500 ms) was followed by a delay, to avoid forward masking. A target digit (in a digital font) was then presented for a duration of 1 to 6 frames (frame duration 11.8 ms), which was followed by a backward visual mask made of random lines presented for 30 frames. An objective response was prompted as to whether the presented digit was even, *e*, or odd, *o*. Finally, following an auditory cue, signalling that the objective response had been made, participants reported subjective experience of the target by pressing one of the buttons 1–4.

presented in a blocked fashion such that the same cue condition would repeat 12 times before a new cue condition was presented. This was done to keep top-down expectations stable over a series of trials and to strengthen them. Whenever a new cue appeared, it was accompanied by a high-pitch tone to inform participants that a new block of cues was coming up. Trials were self-paced, and each trial was initiated when participants pressed the space bar. Counterbalancing was done by creating lists with two instances of each of the possible combinations of digits for 2 (16 combinations), 4 (36 combinations) or 8 (1 combination) digits. These lists were then shuffled and reinitialized and shuffled when they had been emptied.

After the central cue was presented, a black (1.77 cd/m^2) fixation cross appeared for 500 ms, followed by an empty screen for 500 ms. The long temporal gap between cue and target was chosen to minimize any effects of forward masking (Breitmeyer & Öğmen, 2006; Souto, Born, & Kerzel, 2018) or lateral inhibition (Francis, 1997; Petrov & McKee, 2009) that might occur between cue and target, and to provide enough time for participants to process the meaning of the cue. Subsequently, a low-contrast target digit, with a height of 2.5° and a width of 1.3°, brighter than the background (36.5 cd/m^2, 17.7% contrast), was presented for a duration of 1–6 frames (11.8–70.6 ms). A slight jitter was applied to the position of the target digit, randomly drawn from a uniform distribution that fell within ±0.5° of the fixation point. The target digit was followed by a backward pattern mask, which was randomly generated on each trial, consisting of 250 white (115 cd/m^2) lines whose endpoints were randomly chosen from a Gaussian distribution centred at fixation with a standard deviation of 6° of visual angle in both the *x*- and *y*-directions. The mask was presented for 353 ms (30 frames). This was followed by a visual prompt, indicating that the participant should press either *e*, for even, or *o*, for odd, as quickly and as accurately as possible. An auditory tone indicated that the response had been made and signalled that participants should rate their subjective experience using the Perceptual Awareness Scale (Table 1) (Ramsøy & Overgaard, 2004). This was done using the buttons 1–4 (upper-left corner). Each participant performed a total of 864 experimental trials. PsychoPy 1.81.03 (Peirce, 2009) was used to run the experiment. Before the actual experiment was run, 18 practice trials were run with representative target durations, and participants were instructed to use the same criterion for rating subjective experience throughout the experiment. During the practice trials, participants were instructed on how to use the four PAS-ratings and to understand their semantic content such that responses did not simply reflect a four-step rating scale. No Experience was to be used when there was no subjective experience of anything at all, Weak Glimpse when there was a subjective experience of something appearing, but none of its features, Almost Clear Experience when there was a subjective experience with most features clearly seen and finally Clear Experience when there was a subjective experience with clarity of all features (Sandberg & Overgaard, 2015).

2.1.3. Psychometric functions

We modelled objective performance and average PAS Rating by fitting a sigmoid function (Sandberg et al., 2010; Windey, Gevers, & Cleeremans, 2013).

$$f(x) = \mathrm{a} + \frac{b-a}{1+\mathrm{e}^{\frac{c-x}{d}}} \tag{1}$$

The four free parameters of this function represent the following: *a* is the lower asymptote, *b* is the upper asymptote, *c* is the inflexion point of the sigmoid function or *threshold*, and *d* is a measure of the steepness of the curve at the point of inflection. When parameter *d* approaches infinity, the function shifts towards a horizontal line, and when *d* approaches 0, the function shifts towards a step function. A unique function was fitted for each participant and for each of the three levels of No. of Possible Targets (2, 4 or 8). The free

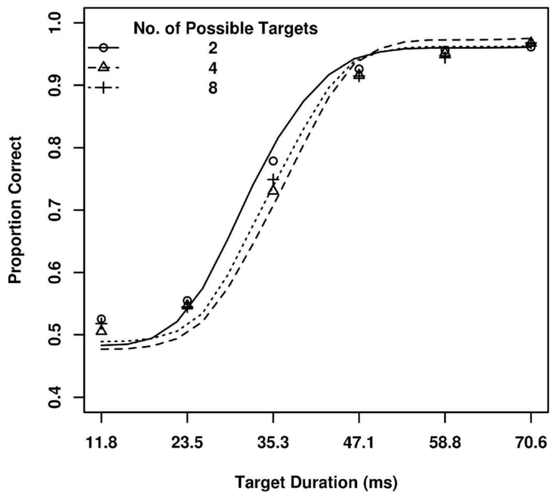

Fig 2. Psychometric curves for accuracy as a function of target duration for different degrees of distinctness of expectations (No. of Possible Targets). No differences were found for any of the four parameters between any of the No. of Possible Targets. The points represent the means of the values on which the curves were fitted. *a, b, c* and *d* were fitted separately for each individual. The curves shown here are based on the means of those individual values.

parameters, a, b, c, d, can be interpreted respectively as minimum accuracy, maximum accuracy, threshold and the linearity of accuracy as a function of Target Duration. The model was fitted by minimizing the error (squared difference between model and data) using the L-BFGS-B algorithm (Byrd, Lu, Nocedal, & Zhu, 1995).

Mixed model analyses (McCulloch & Neuhaus, 2005) were applied to investigate how top-down expectations (No. of Possible Targets) affected subjective experience and objective performance. We performed model comparisons between models that did or did not include the relevant fixed effects and interactions to find the best compromise between an explanatory and a parsimonious model. This was done using the log-likelihood ratio between two models because this ratio approximates a chi-square distribution. A chi-square test can thus be used to assess whether two models differ significantly, where the test statistic is the log-likelihood-ratio and the degrees of freedom is the difference in free parameters of the two models.

3. Results and discussion

3.1. Psychometric functions

As can be seen in Fig. 2, performance accuracy was comparable to the level expected by chance at the shortest target duration, and appeared to reach asymptotic levels of accuracy for target durations of 47.1 ms or longer. Accuracy for each of the three levels of No. of Possible Targets could be modelled by the psychometric function (Eq. (1)) (Fig. 2). For none of the four parameters, however, were differences found between the three levels of No. of Possible Targets. We created mixed models for each of the parameters with Number of Alternatives as the fixed effect. A separate intercept was modelled for each Participant. For all parameters, *minimum accuracy* (a), *maximum accuracy* (b), *threshold* (c), and *steepness* (d), the No. of Possible Targets could be removed without a significant change in log-likelihood; *minimum accuracy*: $\chi^2(2) = 0.128$, $p = 0.922$; *maximum accuracy*: $\chi^2(2) = 0.138$, $p = 0.933$; *threshold*: $\chi^2(2) = 4.27$, $p = 0.118$; *steepness*: $\chi^2(2) = 0.416$, $p = 0.812$.

We combined the data across three number of possible target conditions to fit a single psychometric function. The estimated lower accuracy level, a, was 0.481, the estimated maximum accuracy level, b, was 0.962, and the estimated duration at threshold, c, was 2.81 frames or 33.2 ms. This means that the best approximation of a threshold value for Experiment 1 was at a stimulus duration of 3 frames or 35.3 ms.

We also tested how objective performance changed as the amount of objective evidence increased (Target Duration), binned by the subjective rating of awareness (Fig. 3). The procedure was otherwise the same as above (Fig. 2). The fit for PAS-1 was poor, so only PAS-2-4 were compared. Significant differences were found for *minimum accuracy, a,* and *threshold, c,*: a: $\chi^2(2) = 8.37$, $p = 0.0152$; b: $\chi^2(2) = 4.88$, $p = 0.0873$; c: $\chi^2(2) = 12.5$, $p = 0.00192$; d: $\chi^2(2) = 3.27$, $p = 0.195$. For *minimum accuracy*, the difference was driven by PAS-4 being greater than PAS-3, $z = 2.95$, $p = 0.003$, ($|z| < 1.56$ for the other comparisons.) For the *threshold*, the difference was driven by poorer objective performance for PAS-2 rated trials than for PAS-3, $z = -3.36$, $p < 0.001$ and PAS-4, $z = -2.96$, $p = 0.00304$. This means that the threshold duration for PAS-2 is higher than the threshold for PAS-3 and PAS-4. The difference in a suggests that the baseline performance is lower for PAS-2 and PAS-3 than for PAS-4, but this estimate might be uncertain due to the low frequency of PAS-3- and PAS-4 ratings for short target durations (Fig. 4). Moreover, it is implausible that performance fell significantly below 50% in the case of PAS-3.

The differences found here suggest that PAS is exhaustive, since performance for PAS-1 is not associated with above-chance levels for any degree of objective evidence (Target Duration), as evidenced by the flat curve (Fig. 2). The three other levels of subjective

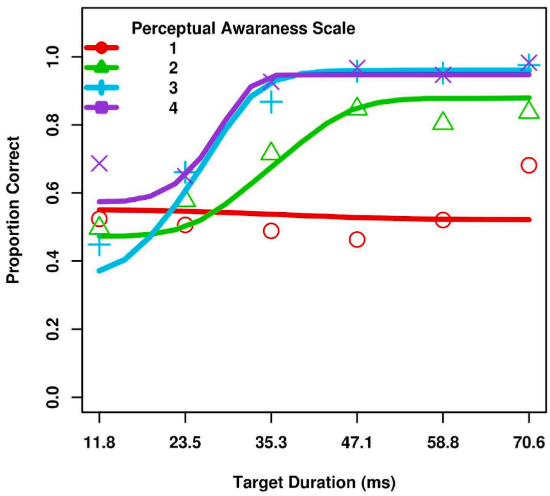

Fig. 3. Psychometric functions for accuracy as functions of subjective experience (PAS). The fit for PAS-1 was bad. The flat curve suggests that no amount of objective evidence (Target Duration) can overcome the absence of subjective evidence (PAS-1). The threshold for PAS-2 is lower than for PAS-3 and PAS-4, evidenced by the right-shifting of the curve. The points represent the means of the values on which the curves were fitted. a, b, c and d were fitted separately for each individual. The curves shown here are based on the means of those individual values.

experience (PAS-2-4) do interact with objective evidence though with clear increases in objective performance as the amount of objective evidence increases. However, this impact of Target Duration varied for the different experiences associated with above-chance performance. PAS-2 required more objective evidence to obtain equal levels of performance, as witnessed by the rightward shift of the curve for PAS 2 (Fig. 3).

Next, we considered how objective performance might vary according to the different numbers of possible targets, and how subjective experience (PAS-rating) might vary with the distinctness of the expectations (No. of Possible Targets).

As might be expected, primarily lower ratings of subjective experience (PAS-rating) were reported when there was little objective evidence (short Target Duration, i.e. 11.8 & 23.5 ms), and primarily higher ratings were reported when objective evidence was strong (long Target Duration, i.e. 47.1, 58.8 and 70.6 ms). At the approximated threshold of 3 frames or 35.3 ms, a more uniform distribution of ratings of subjective experience was found (Fig. 4). Although some studies have claimed to find evidence of the dichotomous all-or-none nature of conscious perception, the present results indicate the importance of identifying the precise experimental conditions to induce threshold levels of behavioural performance. With a stimulus duration of 35.3 ms, we observed about an equal proportion of subjective ratings across the spectrum, whereas at other durations, responses tend to be skewed toward no percept or a clear percept.

To investigate how subjective experience was dependent on the distinctness of expectations, we modelled the number of responses for each PAS-rating as a function of the No. of Possible Targets (2, 4, 8), Target Duration and PAS-rating (1, 2, 3, 4) and the interactions between them. A separate intercept was modelled for each Participant. The number of responses was assumed to follow a Poisson-distribution. The three-way interaction could be dropped without a significant change in log-likelihood, $\chi^2(30) = 34.7$, $p = 0.253$. The interaction between Target Duration and PAS-rating could not be dropped, however, $\chi^2(15) = 14806$, $p < 0.001$, as we observed a significant effect. The interaction between No. of Possible Targets and Target Duration could be dropped, $\chi^2(10) = 4.03$, $p = 0.946$. The interaction between No. of Possible Targets and PAS-rating could not be dropped, $\chi^2(6) = 15.0$, $p = 0.0201$.

The optimized model for modelling the number of responses for each subjective experience thus consists of the interaction between Target Duration and PAS-rating, and the interaction between No. of Possible Targets and PAS-rating. This means that the distribution of subjective experiences (PAS-rating) is dependent on both the objective evidence (Target Duration) and the distinctness of expectations towards the stimuli (No. of Possible Targets).

We investigated the interaction between subjective experience and expectations further. From visual inspection, it seems that the effect of expectation on subjective experience is greatest for the three-frame duration condition, which is closest to the threshold estimated with the psychometric functions (Fig. 2). For each of the Target Durations, we made twelve comparisons (comparing the frequency of PAS 1, PAS 2, PAS 3, PAS 4 among the three levels of expectations, resulting in three comparisons for each). We only report the significant comparisons here. For 3 frames, we found that a greater number of clear subjective experiences (PAS 4) were reported for the distinct expectations (2 Possible Targets) compared to both 4 Possible Targets, $z = 2.66$, $p = 0.00780$, and 8 Possible Targets, $z = 2.99$, $p = 0.00284$. Unexpectedly, we also found that more absences of experience (PAS 1) were reported for distinct expectations (2 Possible Targets) than for indistinct expectations (8 Possible Targets), $z = 2.46$, $p = 0.0138$. However, only the two former tests survived False Discovery Rate (FDR) correction (Benjamini & Hochberg, 1995): $z = 2.66$, $p_{FDR} = 0.0467$; $z = 2.99$,

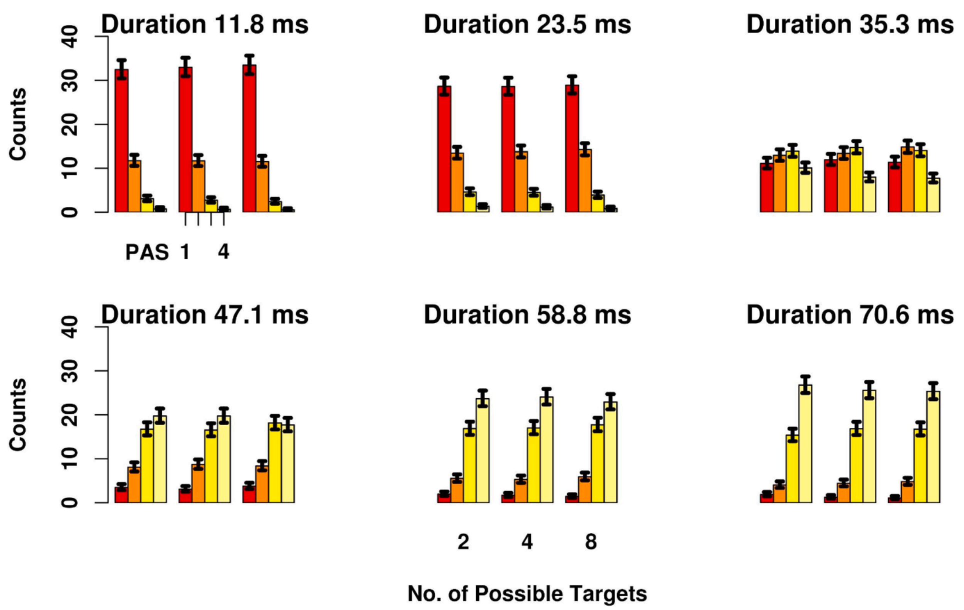

Fig 4. Distribution of PAS-responses for Experiment 1. This summary data is estimated based on a mixed model with the fixed effects: *No. of Possible Targets, Target Duration*, and *PAS-rating* and their interactions. An individual intercept was modelled for each subject, i.e. a random effect. For all distinctnesses of expectations, PAS 1 and PAS 2 dominate when targets are presented for short durations (<24 ms) and PAS 3 and PAS 4 dominate for long durations (>47 ms). Nearest the estimated threshold, (35.3 ms), subjective experience becomes more graded, when expectations are vague compared to when they are distinct. Error bars are 95% confidence intervals. Count responses are assumed to follow a Poisson distribution.

$p_{FDR} = 0.0341$; $z = 2.46$, $p_{FDR} = 0.165$. Note, however, that the FDR-corrected tests were calculated for each of the six frames independently, resulting in 12 tests within each frame. Correcting using all 72 (6 × 12) tests would mean that none survived. In summary, we find suggestive evidence that distinct expectations may result in clearer subjective experiences around threshold. Among the experiences enabling above-chance performance (PAS 2-4) the proportion of graded responses (PAS 2-3) was higher when expectations were less distinct. For 2, 4 and 8 Possible Targets, respectively, the percentages were 72.7%, 77.9% and 78.9%.

Experiment 1 thus provides tentative evidence that the greatest effect of expectation on subjective experience may be found around the threshold. This effect may be confounded by differences in performance accuracy between the different kinds of expectations, which we tested next (Fig. 5).

We modelled Accuracy as dependent on the No. of Possible Targets (2, 4 or 8), Target Duration and PAS-rating (1, 2, 3 or 4) and the interactions between them. A separate intercept was modelled for each Participant. The correct/incorrect responses were assumed to follow a binomial distribution. The three-way interaction could be dropped without a significant change in log-likelihood, $\chi^2(6) = 2.49$, $p = 0.870$. The interaction between Target Duration and PAS-rating could not, however, $\chi^2(3) = 407$, $p < 0.001$. The interaction between No. of Possible Targets and Target Duration could be dropped, $\chi^2(2) = 1.74$, $p = 0.419$, and so could the interaction between No. of Possible Targets and PAS-rating, $\chi^2(6) = 8.68$, $p = 0.192$. Finally, the main effect of No. of Possible Targets could not be dropped, $\chi^2(2) = 6.33$, $p = 0.0424$. The optimized model for accuracy thus consisted of the interaction between Target Duration and PAS-rating and the main effect of No. of Possible Targets.

From visual inspection of Fig. 5, it may be concluded that the interaction between objective evidence (Target Duration) and subjective evidence (PAS-rating) manifested as an improvement in performance accuracy as more objective evidence becomes available with increasing Target Duration. One interpretation of this finding is that with more objective evidence, subjective experience can facilitate more accurate responses (evidenced by PAS-ratings 2, 3 and 4 all getting closer and closer to ceiling the more objective evidence there is). This assumes, though, that subjective experience has a causal impact on objective performance. From the perspective of signal detection theory, however, on each trial there is signal and internal noise, with the strength of the neural response having some variability. Thus, if subjective ratings are read out from the strength of the neural response on a given trial, then greater than average neural responses will be associated with subjective ratings associated with greater clarity *and* better objective performance. This means that we cannot exclude that the hypothesized, and found, interaction between frequencies of subjective ratings and expectations (Fig. 4) is confounded by the main effect of expectations on accuracy.

From the distribution analysis (Fig. 4), however, it seems to follow that a potential effect of expectation on subjective experiences would be strongest around the visual threshold. Restrictive analyses to stimuli durations around threshold (Target Duration: 23.5, 35.3 & 47.1 ms) indicated that the effect might be specific to these stimuli durations. To test this suggestion, we conducted a follow-up experiment aiming at presenting stimuli at the visual threshold while controlling for accuracy.

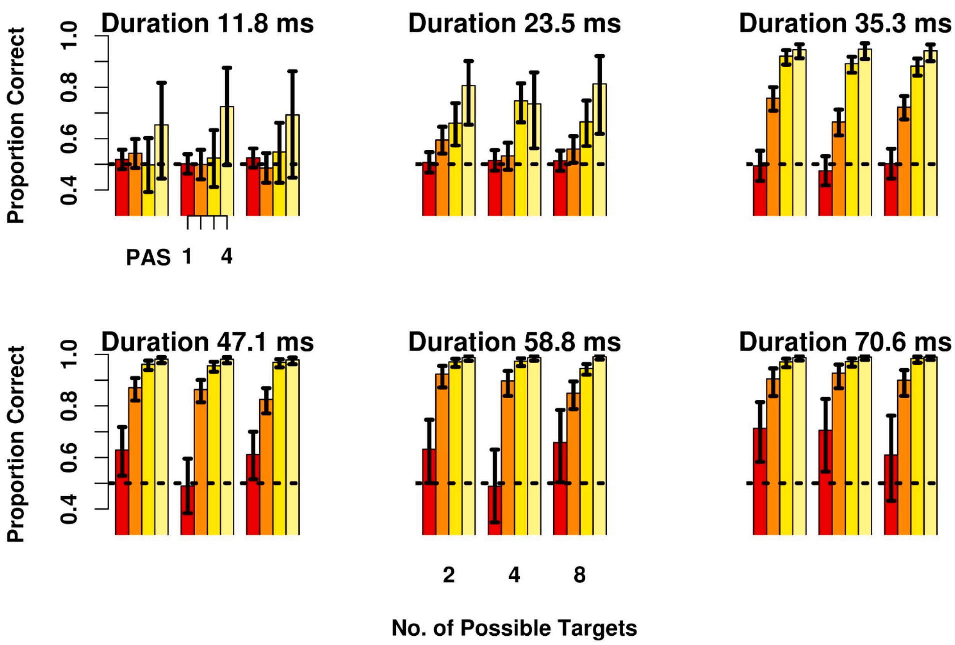

Fig 5. Accuracy of responses in Experiment 1. This summary data is estimated based on a mixed model with the fixed effects: *No. of Possible Targets, Target Duration*, and *PAS-rating* and their interactions. An individual intercept was modelled for each subject, i.e. a random effect. Accuracy was, as expected, dependent on the objective evidence (Target Duration), but also on the interaction between Target Duration and PAS-rating with accuracy increasing more for PAS-ratings 2–4 than for PAS-rating 1. Error bars are 95% confidence intervals. Correct/incorrect responses are assumed to follow a binomial distribution.

4. Experiment 2

4.1. Purpose

The purpose of Experiment 2 was to replicate the statistically significant effects of Experiment 1, and to verify the relationship between Number of Possible Targets and the frequency of clear percepts reported. To strengthen our statistical power for detecting such a posited relationship, we used an adaptive staircase procedure so that more data could be collected at the threshold visibility.

4.2. Methods

4.2.1. Participants

29 participants, 15 women and 14 men, with normal or corrected-to-normal vision, provided informed written consent.

4.2.2. Stimuli and procedure

Participants were seated 45 cm from a CRT-monitor running with a resolution of 1280 × 1024 pixels and a refresh rate of 85 Hz. During this experiment, the target stimulus was always presented for 3 frames, equivalent to 35.3 ms, since this was closest to the estimated threshold from Experiment 1. The contrast of the target stimulus, relative to the background, was adjusted to match the threshold of each individual participant by using the QUEST-algorithm (Watson & Pelli, 1983). The performance level aimed for was 75%. The staircase procedure was performed at the beginning of the study, before we collected the actual experimental trials, which maintained a fixed level of contrast throughout. All other parameters were the same as in Experiment 1.

5. Results and discussion

We found that the clarity of subjective experience depended on the distinctness of the observer's expectations, which was manipulated by the number of possible target digits that could appear. In this follow-up study, we again found that when expectations were clearly focussed on just 2 possible targets appearing, the frequency of Clear Experience reports increased (Fig. 6, left panel, Fig. 4, duration 35.3 ms). The distributions of subjective ratings, when comparing Experiments 1 and 2, were somewhat different though. In Experiment 1, the greater frequency of Clear Experiences reported when expectations were distinct shifted towards graded experiences (PAS 2–3) when expectations were indistinct, whereas they in Experiment 2 these clear experiences were shifted towards increased reports of No Experience (PAS 1). Thus, when expectations were distinct, subjective experience became more clear, and vice versa less clear when expectations were indistinct.

We modelled Accuracy as a function of the No. of Possible Targets (2, 4 or 8) and PAS-rating (1, 2, 3 or 4), and tested for the statistical interactions between these factors (Fig. 6, right panel). A separate intercept was modelled for each Participant. The correct/incorrect responses were assumed to follow a binomial distribution. The interaction could be dropped without a significant change in log likelihood, $\chi^2(6) = 6.64$, $p = 0.355$. No. of Possible Targets could also be dropped without a significant change in log likelihood, $\chi^2(2) = 0.469$, $p = 0.791$. This was not the case for PAS-rating, however, $\chi^2(3) = 1382$, $p < 0.001$. These results provide evidence that accuracy is not dependent on the No. of Possible Targets, but only on the subjective experience as indicated by PAS-ratings. We

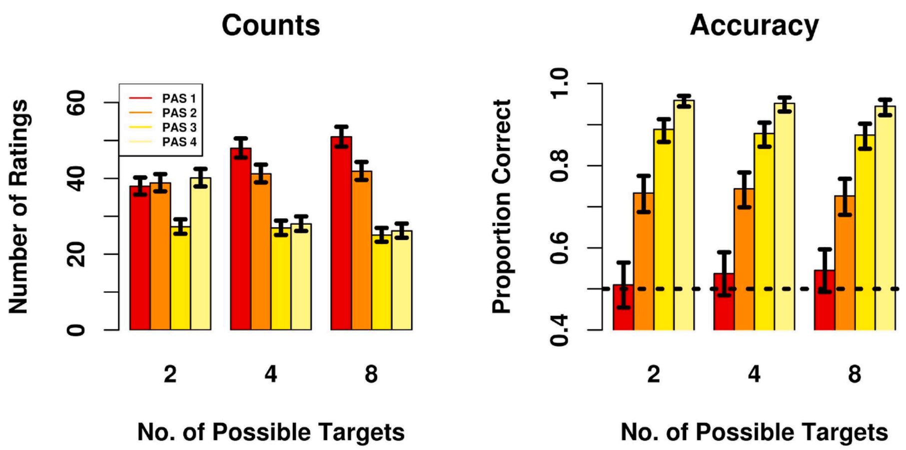

Fig. 6. Distribution of PAS-responses and accuracy of responses in Experiment 2. This summary data is estimated based on mixed models with the fixed effects: *No. of Possible Targets* and *PAS-rating* and their interaction. An individual intercept was modelled for each subject, i.e. a random effect *Left:* when participants could form distinct expectations to forthcoming stimuli (No. of Possible Targets: 2) subjective experiences were rated as clearer than when participants could only form more indistinct expectations (No. of Possible Targets; 4 & 8). *Right:* Accuracy on the other hand was similar across subjective experiences for all levels of expectations distinctness. Error bars are 95% confidence intervals. Correct/incorrect responses are assumed to follow a binomial distribution. Count responses are assumed to follow a Poisson distribution.

investigated how Accuracy was dependent on PAS-rating by comparing neighbouring PAS-ratings. This resulted in a total of three comparisons. PAS-2 had higher accuracy than PAS-1, $z = 27.7$, $p < 0.001$; PAS-3 had higher accuracy than PAS-2, $z = 13.3$, $p < 0.001$; and PAS-4 had higher accuracy than PAS 3, $z = 9.25$, $p < 0.001$. All three comparisons were significant when Bonferroni-corrected; all $p_{\mathrm{BONF}} < 0.001$.

We modelled the number of responses for each PAS-rating as a function of the No. of Possible Targets (2, 4, 8) and PAS-rating (1, 2, 3 or 4) and the interaction between them (Fig. 6, left panel). A separate intercept was modelled for each Participant. The number of responses was assumed to follow a Poisson-distribution. The interaction could not be dropped without a significant change in log-likelihood, $\chi^2(6) = 170$, $p < 0.001$. We investigated the interaction by comparing identical PAS-ratings between the different levels of No. of Possible Targets. This resulted in a total of twelve comparisons. We found fewer PAS-1-ratings for 2 alternatives than for 4 and 8 alternatives, $z = -5.82$, $p < 0.001$, and $z = -7.42$, $p < 0.001$ respectively. We also found more PAS-4-ratings for 2 alternatives than for 4 and 8 alternatives, $z = 7.88$, $p < 0.001$, and $z = 9.17$, $p = 0.001$. None of the remaining eight comparisons revealed significant differences, $|z| < 1.87$ for all z's. The significant comparisons reported were all significant when Bonferroni-corrected and also when FDR-corrected; all $p_{\mathrm{BONF}} < 0.001$ and $p_{FDR} < 0.001$.

Together these results provide evidence that having distinct expectations (2 alternatives) can change subjective experience without this being related to differences in the accuracy of objective performance. Indistinct expectations, involving 4 or 8 Possible Targets, were associated with a greater proportion of graded responses (PAS 2–3) among the experiences enabling above-chance performance (PAS 2–4). For No. of Possible Targets 2, 4, 8, respectively, 62.2%, 70.9%, 71.9% of responses were graded among the above-chance enabling PAS-responses. The relationship observed here is consistent with the pattern observed in Experiment 1, though with lower percentages of graded responses in general. The reason that we calculate gradedness based on the above-chance enabling experiences only is that these are the only ones that conceptually can be graded, i.e the absence of experience cannot be graded.

6. General discussion

The two experiments reported in the current study provide evidence that the distinctness of expectations can influence how clearly one subjectively experiences visual stimuli. With indistinct expectations (No. of Possible Targets: 4 or 8) subjective experiences are more graded (Weak Glimpses, Almost Clear Experience) than for distinct expectations (Figs. 4 and 6). These experiments separate the effects of task difficulty and expectation and thus extend the findings of Nieuwenhuis and de Kleijn (2011) reported in the introduction. Thus, expectations seem to directly influence the quality of subjective experience. In the case of very distinct expectations, stimuli seem to be experienced clearly more often than in the cases where the observer has less distinct expectations. In experimental settings compared to naturally occurring conditions, the range of stimuli tested is usually very limited, which in and of itself can be considered a potential confound when experiments are used to make conclusions about every-day perception. Following the findings reported here, one might expect every-day perceptions to be more graded than what is typically observed in experimental settings. Both experiments also clearly demonstrate that graded perception is often reported when stimulation is presented close to threshold.

We also observe an interaction between the clarity of experience and objective performance The three PAS-ratings that enable above-chance performance, Weak Glimpse, Almost Clear Experience and Clear Experience, are all associated with increases in performance when the degree of objective evidence is increased (Fig. 2) No improvement in objective performance was found as objective evidence increased for No Experience (Fig. 3). This means that even when subjective experiences are given identical ratings, objective differences in stimulation give rise to different response capabilities, with the exception of No Experience. In the former case, content exists for the objective evidence to interact with. In the latter case, there is simply no content that could facilitate goal-directed behaviour. Furthermore, even within the above-chance enabling subjective experiences, different degrees of interactions can be distinguished. Weak Glimpses depend more greatly on objective evidence to facilitate good performance than Almost Clear and Clear Experiences do (Figs. 3 and 5). Even though performance can be explained by a combination of subjective experience and stimulus properties, subjective experiences cannot be fully accounted for in terms of stimulus properties and bottom-up processing alone. The present results indicate that expectations must also be taken into account.

These results motivate a discussion of the relationship between objective evidence and subjective experience. The data from the present experiment indicate that objective evidence and subjective experience are clearly not independent sources when explaining the variability in performance. High degrees of objective evidence co-occur with clear subjective experiences, and low degrees of objective evidence co-occur with weak or absent subjective experiences (Fig. 4). On the other hand, the present data also indicate that they do not perfectly co-vary. Only Almost Clear and Clear Experiences reach ceiling level, whereas Weak Glimpses plateau around 85% accuracy (Fig. 3). No Experience never gets above chance-performance. One may assume that identifying a target stimulus progresses in two stages, a perceptual stage and a decisional stage. In the perceptual stage, evidence is gathered for what is seen, and in the decisional stage, a decision is made as to which (expected) template the perceptual evidence matches the best. In these terms, subjects have veridical insight into the perceptual stage, when they report No Experience, since this does not inform the decisional stage, no matter the prior expectations or the amount of objective evidence. For the above-chance enabling subjective experiences, the present experiment cannot inform whether the effect of expectation takes place at the perceptual stage or the decisional stage. Both are possible – the expectation might bias the perception, or it may lower the threshold for the decision – and both may give rise to a report of clearer experiences when expectations are distinct compared to when they are indistinct. Under all circumstances expectations influence (the report of) subjective experiences. This account does not leave room for subliminal performance, i.e. above-chance performance in the absence of subjective experience. The absence of subliminal performance is however consistent with a recent study by Peters and Lau (2016) where they claim that humans have optimal introspective access to their perceptions. Theoretically, it is possible that the threshold for subjective experience and the threshold for objective performance may differ. For example, if the threshold for subjective experience is higher than that for objective performance, then this would make subliminal performance possible. On the other hand, if humans have optimal introspective access to their perceptions, then these two thresholds should be the same. Peters and Lau (2016) claim to find evidence for exactly this, namely that the thresholds for subjective experience and objective performance are identical. Assuming that this holds generally, we can expand upon this by stating that (veridical) expectations towards forthcoming stimuli seemingly do not cause the objective threshold to become lower than the subjective threshold, as this would otherwise have resulted in above-chance performance for No Experiences.

The finding that both cognitive expectations and stimulus manipulations interact with subjective experience can be understood according to what may be called the cognitive context or concurrent mental states. It is uncontroversial that various elements of the cognitive context influence performance, as is evidenced by the current study and many others (Memory load: Logan, 1979; Rademaker, Tredway, & Tong, 2012; Sweller, 1994); (Task requirements: Posner & Mitchell, 1967); (Attention: Naccache, Blandin, & Dehaene, 2002; Nissen & Bullemer, 1987); (Cognitive strategy: Andersen, Visser, Crone, Koolschijn, & Raijmakers, 2014; Visser, Raijmakers, & Pothos, 2009). Our findings suggest that subjective experience is embedded within a cognitive context in a similar sense. The cognitive mechanism behind the effects of distinct expectations may be that they create an internal template of the upcoming stimulus or perhaps more than one internal template. When a weak sensory stimulus is apprehended as matching the internal template, it has an impact on the clarity of the ensuing subjective experience. In a study (Lamy, Carmel, & Peremen, 2017) that supports such an interpretation, it was found that prior conscious experience increases the likelihood of seeing the next stimulus clearly, as reported on a subjective scale. Interestingly, this did not result in any response priming, that is, response times were no faster when the prime and target were congruent as compared to incongruent. This reported result parallels our own finding that increased conscious experience was not related to an increase in accuracy. That the clarity of the reported conscious experience can increase without an associated improvement in response times or accuracy suggests that conscious experience is independent to some degree of objective performance. This fits well with the model of conscious vision relying on "reverse hierarchies" (Hochstein & Ahissar, 2002), which theorizes that conscious experience differs from automatic feedforward vision. According to this notion, feedforward visual processing is automatic and may strongly drive objective performance, whereas conscious experience is modulated by top-down mechanisms such as prior expectations, whose impact on objective performance may be more subtle. We suggest that prior expectations function as an internal template, and that the strength of this template is dependent on the distinctness of the cue. The fact that top-down expectations had minimal impact on response accuracy is consistent with the notion that bottom-up processing of the visual target and mask was the primary determinant of objective performance in this study. It should be noted that we do not suggest that top-down modulation never influences objective performance, but rather that clearer conscious experiences are not always accompanied by an increase in objective performance. Our suggestion can also be framed in relation to the partial awareness hypothesis (Kouider, de Gardelle, Sackur, & Dupoux, 2010). According to this hypothesis, prior expectations, instilled by the cues, can enable perceptual reconstructions of weak representations. With the present experiment, we cannot conclusively determine whether the prior expectations boost the processing of relevant features of the visual signal or whether they serve to fill in the details in a reconstructive manner after the stimulus is processed. One interpretation is that if the visual signal itself were boosted, one might also expect to find an increase in objective performance.

Potentially, the discussion above has an important bearing on studies that seek to identify the neural underpinnings of subjective experience. Much of the literature pertains to finding *the* neural correlates of subjective experience (Block, 2005; Koch, Massimini, Boly, & Tononi, 2016; Tong, 2003). At least within subjects, this assumes that there is a definite *where* in the brain and a *when* in time that may account for a particular kind of conscious content, including visual consciousness. However, if subjective experience is influenced by and embedded within a cognitive context, it seems reasonable to expect that the same is the case for the corresponding neural correlate. In such cases, it will need to be clarified when a given mental state and its relevant neural counterpart is "part" of the neural correlate of consciousness and when it is not. Some evidence has been found of neural correlates being dependent on the cognitive context. In an EEG study (Melloni, Schwiedrzik, Müller, Rodriguez, & Singer, 2011), evidence was found of expectations affecting the timing of neural responses and of valid expectations correlating with clearer experiences. Furthermore, the arguments above raise the possibility that a neural correlate of consciousness might not be exactly the same from experiment to experiment, as it could depend on several factors, including those that relate to the higher-level cognitive context. Should it be found that neural correlates of conscious experience cannot be fully separated from other cognitive functions, this would serve as evidence for theoretical models that do not claim a strong one-to-one relation between specific brain structures and function (Baars, 1988; Dennett, 1993; Overgaard & Mogensen, 2014; Tononi, 2004, 2008).

Link to online data

The data associated with this article has been shared and be found at the following persistent DOI: 10.17605/OSF.IO/ECXSJ.

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