It's all in your head: Expectations create illusory perception in a dual-task setup

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Abstract

Predictions about the world can guide our perception and action, but they can also misguide us. We developed novel dual-task setups where the participants are occupied by a primary task and are from time to time queried about the phenomenal contents of the auxiliary task. We show that „hallucinating“ the presence of an actually absent stimulus is not an exception, but a common phenomenon (more than 90 % of participants experienced illusory objects at least once). Additionally, in experiment 1 we found a negative correlation between the amount of illusory perceptions and the Autism Spectrum Quotient score. People who scored higher on the questionnaire, were less likely to experience illusory objects. Finally, we observed no effect of spatial attention on expectation-based illusory presence of an object. More generally our results demonstrate that expectations misguide perception when attention is diverted to another task.

Keywords: perception; expectation; priors; illusions; individual differences; predictive coding; autistic traits

1. Introduction

It is well known that prior knowledge can have not only positive but also negative effects on memory (Loftus, 2003). For example, people can falsely remember objects that were not on the scene or words that were actually not included in the learned list (Roediger & McDermott, 1995). Similarly, it has been shown that prior knowledge can create perceptual illusions of object or feature presence. For example, it has been demonstrated that prior knowledge can lead the participants to hear tones that were not played and see letters on a screen that objectively was blank: expectation can create something in the place of nothing (Kuhn & Rensink, 2016; Mack et al., 2016; Tompkins, Woods, & Aimola-Davies, 2016; Aru & Bachmann, 2017; Powers, Mathys & Corlett, 2017).

These findings are well in line with the general idea that our conscious perception is a mixture of and depends on both sensory data and prior knowledge. This intuition has been formalized in predictive coding models of perception, which suggest that perception is determined by the relative weighting of sensory data and expectations (Friston, 2005; Hohwy, 2013; Clark, 2015, O'Callaghan et al., 2017). Any manipulation of this relative weighting will affect whether perception depends more on actual sensory evidence or on prior knowledge. For example, previous research has shown that prior knowledge dominates perception when the sensory data is degraded (Aru et al., 2012; 2016; Powers et al, 2017) or ambiguous (Sterzer, Frith & Petrovic, 2008; Weilhhammer et al., 2018) or when there is a strong prior (Kuhn & Rensink, 2016; Tompkins et al, 2016).

One factor that influences the reliability of sensory data is attention: effects of attention on neural processing and the concomitant behavior have been shown throughout the cortex in humans and monkeys (e.g. Maunsell & Treue, 2006). Attention typically improves veridicality of perception and lack of attention may impair perception. Accordingly, it has been demonstrated that expectations bias perception when attention is diverted away from the stimuli (Mack et al., 2016; Aru & Bachmann, 2017). In these experiments participants were in a dual-task setting, where they were more often asked about stimuli relevant for one task and only rarely about the stimuli relevant for the other task. On some trials stimuli were completely omitted in the rare task, but the participants were nevertheless prompted to answer questions about these actually absent stimuli. It was observed that roughly half of the participants start typing in the letters that were actually not on the screen (Mack et al., 2016) and rate the visibility of these non-existent letters as if they had actually perceived them (Aru & Bachmann, 2017). In the terms of predictive processing these effects can be explained by saying that the way attention is deployed modulates the precision of the sensory data (Feldman & Friston, 2010; Hohwy, 2013; Clark, 2015): if attention is drawn away, the relative weighting of prior expectation over sensory data increases. In other words, when attention is directed away from the stimuli, expectations dominate in forming the percept.

Here we extend this line of research in three important respects. First, we try to better understand why some participants perceive illusory stimuli and others do not. In previous works, 40-50% of participants perceived illusory stimuli while others noticed that the stimulus was actually absent (Mack et al., 2016; Aru & Bachmann, 2017). To better understand the differences between the participants, we use in Experiment 2 two different experimental paradigms on the same participants. This allows us to correlate the values of illusory

perception across tasks. Are the participants who perceive illusory stimuli in one task more likely to perceive illusory stimuli in another task? Is the propensity to „hallucinate“ a trait or task-dependent state? We include the Autism Spectrum Quotient (AQ, Baron-Cohen, 2011) for measuring autism-like traits in a subclinical population. It has been suggested that an imbalance between priors and prediction errors is at the core of autistic traits, more specifically that autism is related to an overweighting of prediction errors (Pellicano & Burr, 2012; Lawson, Rees & Friston, 2014; van de Cruys et al., 2014). These theoretical ideas are at least partly motivated by experimental data showing that autistic participants tend to exhibit reduced susceptibility to certain illusions (Happé, 1996; Pellicano & Burr, 2012; van de Cruys et al., 2014). Extrapolating these findings to our experimental setup we predict that participants with higher scores on the AQ will experience less illusory perception. In other words, we expect that part of the interindividual differences in illusory perception can be explained by the score on the AQ.

Second, we try to better understand the necessary ingredients of an experimental paradigm that is designed to elicit illusory perception. For example, some previous works used a modification of the classic iconic memory paradigm of Sperling (Mack et al., 2016, Aru & Bachmann, 2017) with auditory post-cues. However, it is unclear whether these post-cues are required to generate illusory perception and our preliminary results suggested that they are not (Aru & Bachmann, 2017). In order to separate our task from the standard iconic memory task we included the auditory tone cue in only one of the tasks, but not in others: if illusory perception can also be elicited without these auditory post-cues then we know that they are not crucially contributing to eliciting illusory perception.

Third, we try to understand what type of attention this illusory perception is dependent on. Attention plays a significant role in perception, as it can enhance the perception of attended objects or even result in failure to perceive unattended objects when attention is diverted away (e.g., inattention blindness). In previous experiments (Mack et al., 2016; Aru & Bachmann, 2017) spatial attention and feature-based attention have been confounded. Here, in experiment 1 we use a task where we explicitly manipulate spatial attention. Specifically, we ask whether spatial attention has an effect on the subjective visibility of attended versus unattended stimuli when they are actually missing from the display.

2. Methods

2.1 Apparatus and general procedure

For the computer-controlled experimental display a SUN CM751U CRT monitor with 1024 x 768 pixels resolution and 100Hz refresh rate was used. The experiments were programmed and run on VisionEgg. In all experiments the observers viewed the arrays from a distance of 80 cm.

In all experiments the participants were confronted with a dual task in the main block. In this dual-task setup one task was the “main task”, the other task the “auxiliary task”. On 90% of the trials the participants were queried about the stimuli in the main task, but they were told from the outset that the auxiliary task is also relevant. Participants were always trained on both the main task and the auxiliary task separately before the dual task condition. After

finishing the experiment(s), participants were debriefed about their experience and asked if they had noticed the missing stimuli.

2.2 Experiment 1

2.2.1 Participants and stimuli

Sixteen participants (6 male, 10 female) participated in experiment 1. Participant ages ranged from 18 to 25 years old ($M = 21.38$, $SD = 1.9$). Two participants were left-handed. All had normal or corrected to normal vision. We excluded two participants: one claimed at the debriefing that he had ignored the central cue. The other said that he had explicitly tried to observe the auxiliary task stimulus. In both experiments the sample size was determined by pragmatic considerations.

Face stimuli used in experiments 1 and 2a were selected from the Radboud Faces Database (Langner et al., 2010). To ensure uniformity of stimuli, all images were transformed to grayscale and resized to fit a round shape of uniform size, removing the hairline and leaving only the facial area visible.

2.2.2 Procedure of experiment 1

The main experiment consisted of four blocks of 80 trials (altogether 320 trials). Each trial started with a fixation cross presented in the centre of a grey screen for 1 second, followed by an endogenous-type arrow cue pointing to the left or right of the screen for 150 ms. The cue was valid for 80% of the trials and invalid for 20%. The stimulus was a peripherally presented male or female face with a neutral expression (1.8 degrees of visual angle), surrounded by the lines of a square-shaped figure (4 degrees of visual angle) slightly darker than the background (see Figure 1). The stimulus was presented on the left or right side of the screen for 100 ms, followed by an empty screen for 700 ms. The participants were instructed to fixate on the cross in the centre of the screen and direct their attention to the cued location. On 90% of the trials, the task was to discriminate the gender of the face (male or female). The response keys were S (male) and K (female). On 10% of the trials participants had to rate how clearly they perceived the square on a four-point Perceptual Awareness Scale (PAS) (Overgaard et al., 2006), using the keys A,D,J,L, where “1” corresponds to “no experience of the stimulus,” “2” corresponds to “brief glimpse of the stimulus but could not recognize what it was,” “3” corresponds to an “almost clear impression of the stimulus,” and “4” corresponds to a “clear impression of the stimulus.”

Before the beginning of the experiment, participants were able to practice both tasks separately for 30 trials each. The contrast of the square was varied only during the practice trials of the visibility task, to ensure that participants were using the subjective visibility scale as intended.

On six critical trials (three in the valid and three in the invalid cue condition) no square was presented, although participants were asked to give a perceptual clarity rating. In all three experiments no critical trials were included for the first 80 trials, to ensure that the participants were already used to the task (i.e. that they had built up an expectation about the stimulus screen).

Fig 1: The experimental paradigm of Experiment 1. The display on the top left with the face and the outline of a square around it is associated with two different tasks (bottom row): the participant either has to indicate the gender of the face or rate the visibility of the square positioned around the face. In the single task condition (see methods) all these tasks are trained independently, but in the main experimental phase (dual-task condition) the participant has to be prepared for all these tasks. In the dual-task condition the participants had to perform the face task on 90% of trials, thus ensuring that attention is diverted away from the faint square stimulus. In the critical trials (top right) there was no square, but the participants were nevertheless prompted to rate the visibility of the absent square.

2.3 Experiment 2

2.3.1 Participants

Experiment 2 consists of two parts ran with the same participants recruited for this experiment; 17 participants (6 male, 11 female) participated in experiments 2a and 2b. Participant ages ranged from 21 to 48 years old ($M = 31.41$, $SD = 9.24$). All participants were right-handed and had normal or corrected to normal vision. We excluded two participants who had problems in both experiments (reported no experience of the auxiliary task stimulus even when it was present in E2a and exhibited near random performance in the main task in E2b).

2.3.2 Procedure of experiment 2a

The main experiment consisted of two blocks of 120 trials (altogether 240 trials). Each trial began with the presentation of a fixation cross at the centre of a grey screen for 1 second, followed by two faces (1.7 degrees of visual angle) which simultaneously appeared at the left and right side of the screen (300 pixels from the centre) for 100 ms (see Figure 2). The stimuli were picked from a randomly shuffled list of 32 male and female faces with neutral expressions. Two images of the same face were never presented simultaneously.

The faces were presented in four possible conditions: 1) left and right face upright, 2) left and right face inverted 180 degrees, 3) left face inverted, right face upright, 4) left face upright, right face inverted. The four conditions were presented an equal number of times and shuffled at random per block. During the stimulus screen, the fixation cross was replaced by a small grey Landolt-type square (0.5 degrees of visual angle) with a small gap in one of its four sides. Participants had to maintain fixation at all times. After 700 ms, a response screen appeared. On 90% of the trials, the task was to discriminate whether the two faces were positioned the same way (both upright or both inverted) or differently (one upright, other inverted). The response keys were S (same) and K (odd). On 10% of the trials, the task was to rate the visibility of the Landolt square on a four-point Perceptual Awareness Scale (PAS). Response keys were analogous to E1.

Before the dual task experiment, participants were able to practice both tasks separately for 30 trials each. In the main experiment, participants were instructed to pay attention to both tasks, as there was no indication as to which response would be required until the response screen appeared. On four critical trials no Landolt square was presented, but the participants were nevertheless required to provide a perceptual clarity rating.

Fig 2: The experimental paradigm of E2a. The display on the top left with two faces on the sides and a small landolt in the middle is associated with two different tasks (bottom row): the participant either has to indicate whether the faces have a similar orientation or rate the visibility of the small landolt square. In the single task condition (see methods) all these tasks are trained independently, but in the main experimental phase (dual-task condition) the participant has to be prepared for all these tasks. In the dual-task condition the participants had to perform the face task on 90% of trials, thus ensuring that attention is diverted away from the faint landolt stimulus. In the critical trials there was no landolt, but the participants were nevertheless prompted to rate the visibility of the physically absent stimulus.

2.3.3 Procedure of experiment 2b

The procedure closely follows the experimental setup of Aru & Bachmann (2017; see also Mack et al 2015, 2016).

The stimulus screen contained four circles in the corners and six letters placed on a virtual 2 × 3 matrix presented at fixation for 250 ms (see Figure 3). The letters were drawn from the English alphabet, including all consonants and the letter Y. No letter appeared more than once in any matrix. The circles were vertically color-bisected and the four circles could either be all the same, (for instance, a red left half and a green right half, or vice versa) or one could be oppositely color-arranged, (the red and green halves were reversed). The odd colored circle could appear in any of the four positions.

The experiment consisted of two practice blocks of 50 trials and a main experimental block of 141 trials. In the first practice block, participants were instructed to ignore the letters and only focus on the circles and indicate whether all four color-bisected circles were the same or if there was an odd one. In the second practice block, participants had to focus on the letter task. On the first 20 trials, they had to insert as many of the six letters as they could, maintaining their correct place order, and guess whenever they could not. On the last 30 trials, they had to rate the subjective visibility of the letters on a four-point PAS scale. Here we also manipulated the objective contrast of the letters.

In the dual task experiment, participants were instructed to pay attention to the whole screen and be prepared to perform either task. On 90% of the trials (126 trials) participants had to respond to the circle task. On the remaining trials participants had to either insert the letters they saw (7 trials) or rate their visibility (8 trials), although their objective contrast remained the same. A low tone (500 Hz) post cue signalled performance of the letter task and a high tone (1500 Hz) post cue indicated the circle task.

On four critical trials, no letters were presented, yet participants had to provide a subjective visibility rating. In these critical trials, subjects never had to type in letters, they only rated the visibility of the “letters”. Critical trials were presented in the second part of the experiment at an interval of 20 trials. On the second and fourth critical trial, the post cue tones were exchanged, calling attention to the circle task, despite participants being asked to rate the subjective visibility of the letters. After completing the visual experiments, participants were asked whether they noticed the missing stimulus and the different tone.

The order of experiments 2a and 2b was not counterbalanced for two reasons. First, as in experiment 2b the critical stimuli came in a more predictable fashion and over a shorter time window, we expected that participants might perceive the absent stimuli more often in that experiment. Second, after experiment 2b we had to ask the participants whether they had perceived the wrong tone. Again, as the “wrong tone” is something unexpected we reasoned that after hearing the question the participants might become more suspicious about the real goals of the experiment. Hence, if we would have presented the current experiment 2b before 2a, participants might have expected the absence of stimuli or something else surprising, which would have hindered us from collecting valid data from experiment 2a.

Fig 3: The experimental paradigm of E2b. The display on the top left with circles in the corners and a letter display in the middle is associated with three different tasks (bottom row): the participant either has to indicate whether the circles are similar, type in the letters or rate the visibility of the letters. In the single task condition (see methods) all these tasks are trained independently, but in the main experimental phase (dual-task condition) the participant has to be prepared for all these tasks. In the dual-task condition the participants had to perform the circle task on 90% of trials, thus ensuring that attention is diverted away from the letters. In the critical trials there were no letters, but the participants were nevertheless prompted to rate the visibility of the physically absent stimuli.

2.4 Data analysis

To have a compound measure of illusory perception that equally reflects on the responses given in each critical trial, we added up the visibility ratings of all the critical trials to obtain an illusory perception score. We chose this measure to better illustrate the range of interindividual differences in the extent of illusory perception. However, in order to ensure that analyses conducted with the illusory perception score were representative of the central tendency of participants' answers, we also conducted the same analyses with means and medians which provided very similar results. In experiment 1 the illusory perception score varies between 6 (in each of the 6 times the participant gave the response 1 - "no experience of the stimulus,") and 24 (in each of the 6 times the participant gave the response 4 - "a clear impression of the stimulus.") We also calculated it separately for the

trials with (valid cue) or without (invalid cue) spatial attention (there the illusory perception score can vary between 3 and 12). In the experiment 2 the illusory perception score varies between 4 (in each of the 4 times the participant gave the response 1 - “no experience of the stimulus,”) and 16 (in each of the 4 times the participant gave the response 4 - “a clear impression of the stimulus.”).

All data analysis was performed using R software (<https://www.R-project.org/>; version 3.3.0). The main analyses were done with paired t-tests and repeated measures ANOVAs. To study relations with the autistic trait we also used Pearson’s correlation analysis. Effect sizes were reported with Cohen’s d and generalized eta squared statistic. R package ez was used for rmANOVA.

Complete data and additional materials are available on the project page on the Open Science Framework (<https://osf.io/scfvx/>).

3. Results

3.1 Experiment 1

We observed that in general participants often reported illusory perception: on the critical trials where the square was absent, only one participant never (i.e. on none of the 6 trials) used a visibility rating higher than 1 (“no experience of the stimulus”). Six of the 14 participants saw illusory perception on more than three occasions. Nine participants at least once used the rating 3 “almost clear expression ...” for the absent stimulus. On an average of 50% of critical trials (mean across participants) at least some experience (i.e. a visibility rating higher than 1) of the missing stimulus was reported. (Figure 4-D).

To first test whether our manipulation of spatial attention was effective, we analysed the effect of the cue on the accuracy in the main task. We found a significant difference in correct answers between the valid and invalid condition ($t(13) = -3.96$, $p = .002$, $d = 1.06$; The average correct response in the valid condition was 77.71% and in the invalid condition 62.65%). Therefore, we can say that cues were used and proved helpful for the main task of recognizing faces. We did not analyze reaction times as we had explicitly told the participants to aim for accuracy over reaction times.

Next we analyzed whether the cues also had an effect on subjective visibility (critical trials removed). Visibility ratings provided for the auxiliary task did not differ between the two cue conditions ($t(13) = -0.12$, $p = .905$, $d = 0.03$; the average rating in the valid condition was 2.66, for the invalid condition 2.65). This pattern also emerged in the critical trials where no significant difference between cue conditions was found ($t(13) = -0.69$, $p = .504$, $d = 0.18$; average rating in the valid critical condition 1.90, invalid critical condition 1.69). Taken together, spatial attention did not affect the subjective visibility of the stimuli.

We then investigated whether the visibility of the square in the critical trials is rated differently than in the trials where the square is actually present and whether this effect is dependent on attention (valid vs invalid condition). We observed a significant main effect of trial type on visibility ratings ($F(1,13) = 50.30$, $p < .001$, $\eta^2_G = .521$), but neither an effect of cue condition nor an interaction ($p > .05$). As the contrast of the auxiliary task stimulus was chosen to allow for variation in PAS ratings, and since the main task was generally deemed

more important, it was possible for participants to fail to clearly perceive the square even when it was present and some occasionally gave ratings of 1. On average, such “inattentional blindness” occurred on 12.9% of the trials ($SD = 8.7\%$). We therefore also conducted the same analysis excluding trials where participants had reported no experience of the square (rating 1). The effect of trial type remained significant ($F(1,9) = 24.83, p < .001, \eta^2_G = .34$), which indicates that the perceptual experience from an actual stimulus is stronger than the illusory perception of an absent stimulus. Again, there was neither an effect of attention nor an interaction ($p > .10$)

Next we investigated whether visibility ratings provided in the critical trials were reflective of an overall response tendency during trials where the stimulus was present by conducting a correlation analysis between the illusory perception score and the visibility ratings in non-critical trials across participants. We observed that the correlation was not significant ($r = .52, p = .054$) (Figure 5-A). Interestingly, when we partitioned the trials according to whether the trials were with (valid cue) or without (invalid cue) spatial attention we found that the correlation between the illusory perception score and visibility was significant only in the condition with valid cues ($r = .73, p = .003$), but not with invalid cues ($r = -.10, p = .730$).

We also posed the question whether people who rated higher on the Autism Spectrum Quotient (AQ) were less likely to experience illusory perception. We observed a significant negative correlation between the AQ score and the individual illusory perception score ($r = -.68, p = .007$) (Figure 5-D). This negative correlation was significant for trials with both invalid and valid cues (valid $r = -.60, p = .023$; invalid $r = -.61, p = .02$). It could be argued that this result is caused by the fact that participants with higher AQ scores tend to be more conservative and also give lower visibility ratings in general. However, we observed no correlation between the AQ score and average visibility in trials where the critical stimulus was present ($r = -.24, p = .410$). There also was no correlation between AQ scores and the amount of non-critical trials where participants reported no experience of the stimulus ($r = .32, p = .267$). To compare, we also conducted the correlation analysis between the AQ score and the number of trials with illusory perception (i.e. the proportion of critical trials per subject with reported visibility greater than 1) and confirmed our basic finding of a negative correlation between autism and proneness to illusion ($r = -.73, p = .003$).

Fig 4: Descriptive statistics of illusory perception across all experiments. A-C: Absolute frequency bar plots for the three experiments showing PAS scale visibility ratings provided for each of the critical trials (A - Experiment 1 valid and invalid condition, B - Experiment 2a, C - Experiment 2b). D: Proportion of visibility ratings given in each experiment. E: Proportion of participants that reported some experience of stimulus (rating 2 or higher) during critical trials when no stimulus was presented in each experiment.

Fig 5: A-C Scatterplots with regression line and 95% confidence interval for the average visibility rating and illusory perception score for each experiment. D-F Scatterplots with regression line and 95% confidence interval for the Autism Quotient score and illusory perception score for each experiment.

3.2 Experiment 2

3.2.1 Experiment 2a

As in experiment 1 we observed that participants often perceive stimuli that are physically not on the screen: Only one participant never had illusory perception, but six participants reported illusory perception every time (i.e. on each of the 4 trials); 12 of the 15 participants at least once used the rating - “almost clear expression ...” and six participants reported to have “a clear impression...” of the missing stimulus. On an average of 67% of critical trials participants reported some experience of the stimulus. (Figure 4-D)

We observed a correlation between the illusory perception score and the visibility rating in non-critical trials ($r = .59$, $p = .02$) (Figure 5-B). There was also a significant difference between visibility ratings provided for trials when the square was present compared to when it was absent ($t(14) = 4.25$, $p < .001$, $d = 1.10$, average rating for non-critical trials was 2.98 and for critical trials was 2.25). On an average of 10% of non-critical trials (SD = 11.2%) participants reported no experience of the stimulus. The difference in visibility ratings between the trial types remained significant after excluding the trials where no experience of the stimulus was reported ($t(13) = 4.06$, $p = .001$, $d = 1.08$). The correlation between AQ and illusory perception score was not statistically significant ($r = -.36$, $p = .183$) (Figure 5-E).

Conducting a correlation analysis with the the number of trials with illusory perception closely mirrored this result ($r = -.40$, $p = .135$)

3.2.2 Experiment 2b

Participants reported somewhat less illusory perception than in E2a, there were three participants who did not have illusory perception at all. This might happen because in E2a the 4 stimulus absent trials were randomly dispersed among 160 trials whereas in E2b they were presented every 20 trials among 80 trials -- they arrived at regular intervals which may have drawn attention to them. Six participants had illusory perception in more than half of the trials. Seven of the 15 participants at least once used the rating - "almost clear expression ..." and four participants reported to have "a clear impression..." of the missing stimulus on at least one trial. Participants on average reported some experience of the missing stimulus on 48% of the critical trials (Figure 4-D).

In this experiment we again observed a significant positive correlation between the illusory perception score and the visibility ratings in the non-critical trials ($r = .748$, $p = .001$) (Figure 5-C). There was a significant difference between visibility ratings provided for trials when the letters were present compared to when they were absent ($t(14) = 8.26$, $p < .001$, $d = 2.13$, average rating for non-critical trials was 2.95 and for critical trials it was 1.85). Participants reported no experience of the letters when they were actually present on an average of 16.7% of trials (SD = 20.4%). Again, we found that similar results emerged when only analysing trials with ratings higher than "no experience..." ($t(11) = 4.00$, $p = .002$, $d = 1.15$). The correlation between AQ and illusory perception score was not significant ($r = -.34$, $p = .217$) (Figure 5-F). The result was similar when correlating the AQ score with the number of trials with illusory perception ($r = -.27$, $p = .329$).

In this experiment we also manipulated whether the post-cue tone was correct or not. Only one person reported that he noticed the wrong tone, all other 14 participants had no idea that on two occasions the wrong tone was used.

3.2.3 Comparison of E2a and E2b

As E2a and E2b were conducted by the same participants, we could also analyse the correlations across the tasks. We observed a significant correlation between the visibility ratings in both tasks ($r = .59$, $p = .022$) but no correlation between the illusory perception scores ($r = .48$, $p = .069$).

The visibility ratings on the non-critical trials did not differ significantly between the two auxiliary tasks ($t(14) = -0.08$, $p = .941$, $d = 0.02$) and there also was no significant effect for trials where the stimuli were in fact missing (i.e. on critical trials) ($t(14) = 2.01$, $p = .065$, $d = 0.52$, average for missing Landolt square in E2a 2.25, for letter matrix in E2b 1.85). Despite the non-significant difference we consider it possible that the absence of stimuli in E2b was somewhat easier to notice due to stronger contrast (black letters on white background, compared to dark grey square on a light grey background) and a longer display time, or because of the regularly distributed critical trials. Indeed, as can be seen on Figure 4-C in E2b the first critical trial tended to be rated with a higher visibility rating when compared to the last critical trial ($t(14) = 2.58$, $p = .022$, $d = 0.67$).

We also could analyse the difference in accuracy of the main task. We observed that the main task in E2a was easier than that of E2b ($t(14) = 3.95$, $p = .001$, $d = 1.02$, average accuracy for the face task 88.40%, for the circles task 75.29%). Interestingly, more “hallucinations” were reported in the easier task (Figure 4-D).

4. Discussion

According to modern models of perception, our experience is always a mixture of expectations and the incoming sensory data (Hawkins, 2004; Friston, 2005; Hohwy, 2013; Clark, 2015, O’Callaghan et al., 2017). These expectations can aid and guide perception, but being based on prior experience they also can misguide perception if the present sensory data is not in agreement with prior knowledge. Accordingly, over recent years it has been demonstrated that expectations can override sensory information and create perception of stimuli that are objectively absent (Kuhn & Rensink, 2016; Mack et al., 2016; Tompkins et al, 2016; Aru & Bachmann, 2017; Powers et al, 2017). In the present study, we systematically examined this effect in three experiments. We studied how expectations can create illusory perception when attention is diverted away from the stimuli. In all experiments participants were in a dual-task condition, where they were more often inquired about stimuli relevant for one task and only rarely about the stimuli relevant for the other task. On some trials stimuli were completely omitted in the rare task, but the participants were nevertheless asked to rate the visibility of these actually non-presented stimuli.

In all experiments we observed that most participants reported to have consciously perceived stimuli that were in fact missing from the display. Some participants even reported to have had an “almost clear impression of the stimulus” or even “a clear impression of the stimulus” that was objectively not there on the screen. We observed that high visibility ratings for task-irrelevant stimuli that are objectively absent are the norm and not the exception. We now come back to the questions posed in the introduction.

4.1 *Why do some participants perceive illusory stimuli and others do not?*

A key question that emerged from earlier research is why some participants perceive whereas others fail to perceive the absence of the stimuli (Mack et al., 2016; Aru & Bachmann, 2017). Here we demonstrated that if there are more trials with stimuli absent, most participants use the visibility rating as if they had perceived illusory objects - more than 90% of the participants at least once rated the non-existent stimulus with a visibility rating higher than “no experience of the stimulus”. Still we observed that participants differ in the extent of occurrence of illusory perception (Figure 4-E). This leads to the question, which traits could explain these interindividual differences. For example, the individual variance could be associated with differences in the extent of the modulation of perception through expectations, as some people might be generally more inclined to rely on prior information than others (Tulver et al., in preparation). To investigate this issue, in Experiment 2 we used two different experimental paradigms on the same participants. This allowed us to correlate the values of illusory perception across tasks. With our final sample of 15 participants the correlation between the illusory perception scores of the two tasks did not reach significance ($r = .48$, $p = .069$). This might have been due to the fact that there were notable differences between E2a and E2b. For example, the main task in E2a was much less difficult (average accuracy $M = 88.40\%$, $SD = 8.84\%$) than in E2b (average accuracy $M = 75.29\%$, $SD =$

12.01%) or E1 ($M = 75.20\%$, $SD = 6.92\%$) which may have contributed to differently distributed attentional resources to the auxiliary task.

In all experiments we also measured the participants' personality aspect by administering a questionnaire about autistic traits, the Autism Spectrum Quotient (AQ, Baron-Cohen, 2011). Based on previous ideas we conjectured that the AQ might at least partly explain the interindividual variability in the amount of illusory perception. Indeed, in E1 we observed a significant negative correlation between the score on the autism questionnaire and the amount of illusory perception. In other words, participants who had higher scores on the autism questionnaire gave lower visibility ratings to the absent stimuli. The correlation suggests that people with higher scores on the autism questionnaire perceive the world in its sensory detail more correctly. This finding is in line with the conjecture that autism is related to an enhanced weighting of sensory information over priors (Pellicano & Burr, 2012; Lawson, Rees & Friston, 2014; van de Cruys et al., 2014). However, this correlation between the autism questionnaire and the illusory perception score was found neither in E2a nor in E2b (see Figure 5). We presently do not know why this correlation between the score on the autism questionnaire and the amount of illusory perception was observed only in E1, but not in the other experiments. In any case, both theoretically and experimentally there seems to be a link between the autistic traits and the effects expectations have on perception (Pellicano & Burr, 2012; Lawson, Rees & Friston, 2014; van de Cruys et al., 2014), which needs to be explored further. Another trait, not studied in the present experiments, which could partly explain why some subjects perceive more illusory percepts and other do less, is delusion proneness (Stuke et al., 2018).

4.2 The requirements for eliciting illusory perception

Some previous works studied illusory perception with experimental paradigms classically designed to study iconic memory (Mack et al., 2016, Aru & Bachmann, 2017): critical stimuli were letters and tones were used as post-cues to indicate whether participants should perform the main task or the auxiliary task on the letters. However, we had observed in our earlier study that the participants are not actually using the tones (Aru & Bachmann, 2017), a finding also replicated here. In the present experiment we asked the participants whether they heard the wrong tone and although it was played twice, only one participant out of fifteen noticed the wrong tone. Both the data and subjective reports in debriefing revealed that participants only use the response screen as the post-cue: they effectively ignore the tone and reply to whatever is asked on the response screen.

In the other tasks (E1 and E2a) there was no tone at all. Furthermore, in order to separate our task from the iconic memory tasks the response screen was presented only 700 ms after stimulus offset, which is usually considered to be too long for any iconic memory effects (Coltheart, 1980). Nevertheless in these experiments without the auditory post-cue we qualitatively replicate the findings from an "iconic memory" setup (Mack et al., 2016, Aru & Bachmann, 2017). Hence, the results presented here clearly demonstrate that the effect is not specific to an iconic memory task. Rather, illusory perception can be reliably elicited and studied in any dual-task setup where one task is more important than the other.

4.3 The role of spatial attention in illusory perception

Based on previous research one could predict that attention should increase the veridicality of the percept and hence decrease the amount of illusory perception, while in the absence of attention participants tend to overestimate the visibility (e.g. Rahnev et al., 2011). Furthermore, the predictive coding theory makes a strong prediction that if attention is drawn away, the relative weighting of prior expectation over sensory data should increase. Hence, in the invalid attentional cueing condition there ought to be more illusory perception (Feldman & Friston, 2010; Hohwy, 2013; Clark, 2015).

However, in the current study we did not observe an effect of spatial attention on illusory perception. We cannot draw strong conclusions from this null effect as the nonsignificant effect of spatial attention can also be attributed to the lack of power: there were only three trials for both valid and invalid conditions. Hence, a straightforward idea would be to lengthen the experiment, have critical trials altogether more often and / or use large samples. However, it might not be possible to conduct longer experiments with more trials as participants might notice the fact that stimuli are absent. In fact this is what we saw in experiment 2b where the critical trials were more close together, separated by 20 trials - participants had a lower illusory perception score for this experiment and rated the visibility of the last critical trial lower than they did the first. On the other hand, in a different way this supports the stance that „hallucinating“ is more common when attention is weak because when participants learn to notice that stimuli can be absent they also begin to pay more attention to „the possible absence of a stimulus“. In any case, our present results tend to be consistent with the general idea that attention and subjective awareness mechanisms are autonomous (Aru & Bachmann, 2013; Bachmann, 2006; Mord & Bachmann, 2011).

4.4 Illusory perception or misguided decision making?

Finally we can turn to the thorny question whether participants in our experiments indeed perceived the illusory stimuli or whether they simply report as if they had done so. In other words, do expectations indeed cause illusory perception or do they “simply” affect decision making?

In our experiments we captured conscious experience with PAS ratings: participants were supposed to rate the visibility of the perceived stimuli. For visibility ratings there is no behaviorally correct answer and hence we cannot expect the participants to always truthfully report their experience; we also cannot control the correctness of their response. However, in the objective sense the “correct” and “truthful” answer in the stimulus absent trials would have been “no experience of the stimulus”. The subjects did not provide that answer: on more than half of the critical trials the participants rated the visibility of the absent stimuli with a higher rating than “no experience of the stimulus”. Did this rating reflect perception or was it misguided decision making? In particular, in an experimental setup like this it is possible that in the critical trials the participants are unsure of what they saw but then simply decide according to their general tendency to respond. For example, a participant who in general tends to respond more often with “almost a clear impression ...” and a “clear impression ...” rather than with the other categories might in these critical trials with no stimulus simply also use the same buttons. In general we indeed observed that the illusory perception score was correlated with the visibility ratings across participants. In other words, the participants who generally gave higher visibility ratings also reported more illusory perception. This correlation was significant in E2a and E2b. In E1 the correlation was only significant in the trials with

spatial attention (valid cue condition), but not without (invalid cue condition). These correlations suggest that part of the illusory perception might be explainable by the decision bias. However, even those participants who were more conservative about their visibility ratings, reported illusory perception. Moreover, during debriefing in the end of the experiments, many participants were genuinely surprised about the fact that there were no stimuli presented on several trials. (Introspective experience of some of the present authors also suggests that the phenomenal quality of illusory perception is a genuine perceptual effect.)

In principle, one could view the present results through the lens of signal detection theory: as critical trials constitute only 2-3% of trials participants would have a very high base-rate for assuming that the critical stimulus is there on the screen. Hence, they might adopt a criterion for deciding on almost every trial that the stimulus is present and rate the visibility accordingly. However, we feel that the SDT framework is not appropriate to be applied to illusory perception in a study like ours. The main reason for this belief is the fact that within the SDT framework there is simply no room for perceptual experience that is generated by expectations independently of the stimulation: within SDT there are “signal” and “noise” (and “criterion”), but neither of them corresponds to “illusory perception generated by expectations”. We acknowledge that one could take the SDT perspective and say that the high PAS ratings in trials where the stimulus is absent are simply “false positives” generated by “noise”, but similarly one could also propose that the ratings are based on illusory “signals” generated through expectations. The brain clearly can create perceptual phenomena that are not real signals of the environment, but that are also not noise in terms of psychological reality. For example, pathological hallucinations (e.g. Sacks, 2012) are for the person who experiences them real, vivid and perceptually rich. They are not noise, but they are also not “signals” in the SDT sense because, technically, signalling the actually absent sensory stimulus-signal must be subsumed under the concept of noise in SDT. We contend that the perceptual experiences of our participants are more akin to hallucinations than to “signal” or “noise” of the SDT. Hence, while we think that SDT can still be useful for understanding objective perceptual detection *behavior*, we feel that the SDT is not the correct tool for analysing perceptual phenomena generated by expectations, including illusions (see also Bachmann, 2004, on this matter). Eventually new tools and experimental paradigms will be needed for dissociating perceptual phenomena from decision making (see Bang & Rahnev, 2017 and Fritsche et al., 2017 for clever experimental manipulations for dissociating perception and decision making).

4.5 Future work

The present experiments and results were in several aspects unsatisfying. First, although we considerably increased the amount of critical trials compared to our own previous work (Aru & Bachmann, 2017), we still only had maximally 6 critical trials per participant, which severely restrict the analysis and conclusions that can be drawn from these data. For example, in the work of Powers et al (2017) the authors were able to collect tens of trials with “hallucinations”. However, their stimuli were close to the perceptual threshold, compared to our stimuli that were themselves clearly visible (i.e. with a clearly above-threshold contrast) and whose absence might therefore become easier to notice with every repetition. To allow for more critical trials where the absence of a stimulus would go unnoticed, one could also consider an experimental paradigm where the working memory load is manipulated (e.g.,

Lavie & De Fockert, 2005). Having more trials could help to address and answer further questions that currently remain unanswered. For example, does perceiving the absence of the critical stimulus affect the subsequent visibility ratings of both absent and present critical stimuli? If there is an expectation built up about the presence of the stimuli, which is then suddenly violated, this should re-calibrate the expectations and hence influence the combination of priors and sensory data on the next trials.

The second problem of the current experiments is that although we had three separate experiments, all of them were with low statistical power because of the small sample size. Hence, we could not make a strong conclusion about the relationship of autistic traits and illusory perception which only exhibited a significant correlation in one of the three experiments. We foresee the need for a larger study that could provide more conclusive results. We hope that the current experiments have at least highlighted the ubiquity of interindividual differences in susceptibility to illusory perception and shown the promise and potential of a multi-experiment approach for their examination.

Finally, the present results are probably not enough to convince a skeptical reader that expectations indeed induced illusory perception: although we have shown that illusory perception is very common in such dual-task setups, we have not managed to exclude the possibility that expectations might have had their impact only during the post-perceptual decision stage. The question whether expectations and prior knowledge indeed affect perception (Lupyan, 2015) or do not (Firestone & Scholl, 2016) remains a central question for cognitive (neuro)science.

5. Conclusions

Illusory perception is the price to pay for having a predictive brain. Here we demonstrated that illusory perception can be reliably elicited and studied in dual-task setups where one task is the main task. We found that over 90% of participants reported a subjective experience of the auxiliary task stimulus when it was actually absent.

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