The Role of Top-Down and Bottom-Up Processing in Auditory False Perceptions: A Signal Detection Analysis

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Abstract

There is a tendency in the literature to find people with a high hallucination proneness to have significantly lower response bias but no significant difference for sensitivity compared to people with low hallucination proneness, when performing a signal detection theory (SDT) task. However, results have varied across studies, and the relation is poorly understood. We wanted to increase our understanding by investigating the effect of different levels of semantic expectation and different types of noise on hallucinatory reports among those with high and low hallucination proneness. A large student sample was screened using a revised version of the Launay-Slade Hallucination Scale (LSHS). Students with high and low hallucination proneness were asked to take part in the second phase of the study. In this phase they performed an auditory SDT task where both the semantic expectation of sentences and the noise were manipulated. Participants also completed measures of perception anomalies (Cardiff Anomalous Perceptions Scale), fantasy proneness (Creative Experiences Questionnaire), suggestibility (Multidimensional Iowa Suggestibility Scale), aberrant salience (Aberrant Salience Inventory), and encoding style (Encoding Style Questionnaire). Results showed that participants in the high hallucination proneness group had a lower response bias compared to participants in the low hallucination proneness group when there was a combination of a high level of semantic expectation and Bergen noise. This suggests that both bottom-up and top-down factors are needed to elicit auditory hallucinatory experiences. Furthermore, hallucination proneness, aberrant salience and encoding style all had significant, negative correlations with response bias, indicating that they could all be implicated in the occurrence of auditory hallucinatory experiences.

Key words: auditory hallucinations, signal detection theory, white noise, top-down processing, bottom-up processing.

Sammendrag

Det er en tendens i litteraturen til å finne at folk med høy hallusinasjonstendens har signifikant lavere respons bias, men ingen signifikant forskjell for sensitivitet sammenlignet med folk med lav hallusinasjonstendens, når de utfører en signaldeteksjonsoppgave. Til tross for den generelle tendensen har resultatene variert på tvers av studier, og forholdet er lite forstått. Vi ønsker å øke vår forståelse ved å undersøke effekten av ulike nivåer av semantisk forventning og ulike typer støy, på hallusinasjonsrapporter blant personer med høy og lav hallusinasjonstendens. Et stort utvalg studenter ble forhåndstestet ved å bruke en revidert versjon av Launay-Slade Hallucination Scale (LSHS). Studentene med høy og lav hallusinasjonstendens ble spurt om å ta del i den andre fasen av studien. I denne fasen utførte de en auditiv signaldeteksjonsoppgave hvor både den semantiske forventningen til setningene og støyen var manipulert. Deltakerne utførte også målinger av persepsjonsavvik (Cardiff Anomalous Perceptions Scale), fantasitendens (Creative Experiences Questionnaire), suggestibilitet (Multidimensional Iowa Suggestibility Scale), avvikende betydning (Aberrant Salience Inventory), og innkodingsstil (Encoding Style Questionnaire). Resultatene viste at deltakere i høy hallusinasjonstendensgruppen hadde en lavere respons bias sammenlignet med lav hallusinasjonstendensgruppen når det var en kombinasjon av høyt nivå av semantisk forventning og Bergenstøy. Dette peker på at både bottom-up og top-down faktorer er nødvendige for å fremkalle auditive hallusinasjons-opplevelser. Videre hadde hallusinasjonstendens, avvikende betydning og innkodingsstil alle signifikante negative korrelasjoner med respons bias, noe som indikerer at de alle ser ut til å være impliserte i forekomsten av auditive hallusinasjons-opplevelser.

Nøkkelord: auditive hallusinasjoner, signaldeteksjonsteori, hvit støy, top-down prosessering, bottom-up prosessering.

Preface

The initial idea for this project came from my supervisor Julien Laloyaux, and I was lucky enough to be able to take part in this complex and exciting field of study. Also working on this project was master's student Elena Sørvig, and even though we worked separately we had a frequent interaction during the duration of the project. I appreciated our good cooperation and many fruitful discussions during these months, and our exchange of knowledge has been indispensable. Although the project was Mr. Laloyaux's idea, I was warmly included in the development of the study, with a close dialogue and weekly meetings. Moreover, I was able to take part in every step of the research process, from applying for ethical approval, to the development of experimental material and testing of participants. To be so involved in every part of the study has been time consuming and challenging, but it has also given me invaluable experiences that has furthered my academic development.

I would like to thank my supervisor Julien Laloyaux for bestowing great confidence and faith in me during the entire research process and allowing me to take an active part in the study. It has truly been an educational experience to be a part of this research project, and I greatly appreciate the practical experience and in-depth knowledge it has given me. I would also like to thank Elena Sørvig for being a resourceful and supporting fellow student on the project, as well as being a good academic discussion partner. Lastly, I would like to thank the University of Bergen - Department of Biological and Medical Psychology, and NORMENT: Norsk senter for forskning på mentale lidelser for the economic support we received for this project.

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Auditory hallucinations are “auditory experiences that occur in the absence of a corresponding external stimulation and which resemble a veridical perception” (Waters et al., 2012, p. 683), such as hearing someone talk when nobody is around. Auditory verbal hallucinations (AVHs) have a high prevalence in psychiatric disorders, particularly in people with a schizophrenic diagnosis, where the prevalence have been estimated to be between 40% and 80 % (Larøi et al., 2012). Traditionally, the schizophrenic population has been used for the study of AVHs (Waters, et al., 2012). However, AVHs are also reported by patients with other psychiatric disorders, such as bipolar disorder and borderline personality disorder, as well as patients with neurological disorders, such as Parkinson`s disease and epilepsy (Waters, et al., 2012). Furthermore, AVHs are prevalent among otherwise healthy individuals. An estimate of roughly 7% of the general population experience AVHs (Linscott & van Os, 2013; van Os, Linscott, Myin-Germeys, Delespaul, & Krabbendam, 2009). Unlike patients, AVHs in the non-clinical population occurs less frequently, and mostly under demanding circumstances such as stress and sleep deprivation (Larøi, et al., 2012). Honig et al. (1998), comparing two clinical groups (patients with schizophrenia and dissociative disorders) with non-clinical controls, reported that while control individuals felt in-control of the voice-hearing experience, this was not the case for the patient groups. Moreover, the prevalence of negative voices was significantly higher in the two patient groups compared to the non-clinical group (100% in schizophrenia and 93% in dissociative disorder, and 53% in non-clinical participants). The patient groups were also more afraid of the voices, the voices were more critical and troublesome, and they disturbed their daily life. In another study, Daalman et al. (2011) found that when nonclinical participants and individuals with psychosis were compared, the individuals with psychosis scored higher on more negative content, higher frequency, less controllability, longer duration, and higher disruption and distress in the daily life. Nevertheless, there is a certain degree of similarity between AVHs in the non-clinical and the clinical populations, and they tend to be similar in terms of nonself recognition, perceived location of voices, number of voices, loudness and personification (Daalman, et al., 2011; Waters, et al., 2012). As Larøi, et al. (2012) points out, the non-clinical voice-hearers are not categorically different from the clinical voice-hearers when it comes to phenomenological differences, rather they both exist on the same spectrum of severity. That the psychosis phenotype is expressed at levels below its clinical manifestation is a long-standing notion, and it is often referred to as psychosis proneness, schizotypy, psychotic experiences or at-risk mental states. This implies that the psychosis phenotype is a dimensional phenomenon that exists on a continuum with normal functioning. The continuum-approach assumes that experiencing these psychosis symptoms, such as hallucinations, is not necessarily related to the presence of a psychosis disorder. The presence of a disorder is dependent on symptom factors such as frequency, intrusiveness and psychopathological co-morbidities, as well as coping, illness behaviour, societal tolerance and the degree of associated developmental impairment (van Os, et al., 2009). As both clinical and non-clinical voice-hearers are on the same continuum, the study of non-clinical voice-hearers can be helpful in exploring and discovering the cognitive mechanisms that underlie the origin of hallucinations without the interference of confounding variables such as medication, hospitalization and cognitive deficits, present in the patient population (Vercammen & Aleman, 2010).

Findings on AVHs from neuroimaging studies have been variable, but the tendency is that instances of AVHs coincide with activation in areas of the frontal lobe, such as anterior cingulate cortex (ACC) and inferior frontal gyrus (IFG), and in temporal lobe areas, such as superior temporal gyrus (STG) (Moseley, Fernyhough, & Ellison, 2014). Primary auditory cortex (PAC), secondary auditory cortices, such as Wernicke´s area and the temporoparietal junction (TPJ), and the planum temporale (PT) are all encompassed in the STG. This illustrates the importance of STG in auditory processing, and studies have found that schizophrenic patients with AVHs have tonic hyperactivity in left STG. People who experience AVHs have also been shown to have a reduced activation of PAC during external auditory stimuli, but increased activation to internally generated stimuli (i.e. AVHs), as well as reduced attenuation during inner speech, in auditory cortex (Moseley, et al., 2014). Related to this is a study by Barkus, Stirling, Hopkins, McKie, and Lewis (2007). They did a three-phase study where they recruited participants with high, medium, and low hallucination proneness to complete a task designed to elicit hallucinatory experiences. Eight of the high hallucination proneness participants who reported a high number of hallucinatory experiences, underwent a similar task in a functional magnetic resonance imaging (fMRI) scanner. Patterns of activation during hallucinatory reports in the fMRI displayed activation in the superior and middle temporal cortex. This suggests that auditory hallucinatory experiences in non-clinical populations are mediated by similar cerebral activation patterns as identified during hallucinations in individuals with schizophrenia. The authors showed that similar brain areas are activated during false perceptions (perceiving a signal in an ambiguous situation when no signal is presented) in high hallucination-prone individuals, and during auditory hallucinations and inner speech in a schizophrenic population. A similar study found that clinical and non-clinical groups have similar brain activation during AVHs, as measured with fMRI (Diederen et al., 2012).

Cognitive Model of AVH

To date, many cognitive mechanisms have been related to AVHs, and it is unclear exactly how AVHs emerge. According to the most recent model of auditory hallucinations (Waters et al., 2012) they emerge through an interaction between bottom up (i.e. neural activations) and top-down processes (i.e. the influence of expectations, existing beliefs and understandings on perceptions). These processes rely on two types of functional brain systems. The bottom-up system involves the basic signal for auditory hallucinations, that is the salient auditory stimuli. This is thought to be caused by a hyperactivation of the auditory cortex, which then generate aberrant auditory signals. The second functional brain system, i.e. top-down activity, has to do with the influence of attention, cognitive control capacity, prior knowledge and experiences, and emotional processes on the form, content, and meaning of the auditory hallucinations. This shapes a personalized perception of reality (Waters, et al., 2012). The two processes may lead to a deficit in signal detection, that is detecting signals in ambiguous conditions. AVHs are essentially perceptions, and deficits in detecting signals can produce increased detection of salient or ambiguous signals, and increased likelihood of the signal being accepted as real. Furthermore, the faulty intentional inhibition mechanisms fail to suppress this information and it becomes functionally autonomous. This would lead to a failure in effectively containing and controlling the onset and frequency of these auditory signals. The likelihood of experiences like these being repeated is increased over time due to expectations and hypervigilance (creating a cognitive cue). This may then lead to increased biases and a reduction in threshold for accepting a signal as being real. Top-down factors determine the content of the AVH, before, finally, state and trait characteristics determine the meaning of the AVH by influencing how the top-down factors are interpreted (Fig. 1) (Waters, et al., 2012). However, most prominent for the arise of AVHs are bottom-up and top-down processes, and each of these two functional brain systems will be looked at in turn.

First, we have the salient auditory stimuli that provides the basic signals for AVHs. These are anomalous activations that might be determined by internal conditions (i.e. emotions) and/or environmental conditions. The consequence of the aberrant signals is unexpected intense sensory information caused by the auditory signals exceeding the perceptual threshold. This will bias internal material toward being perceived as arising from external factors and being separate from one’s internal mental process. Furthermore, the rate of firing of neural activation

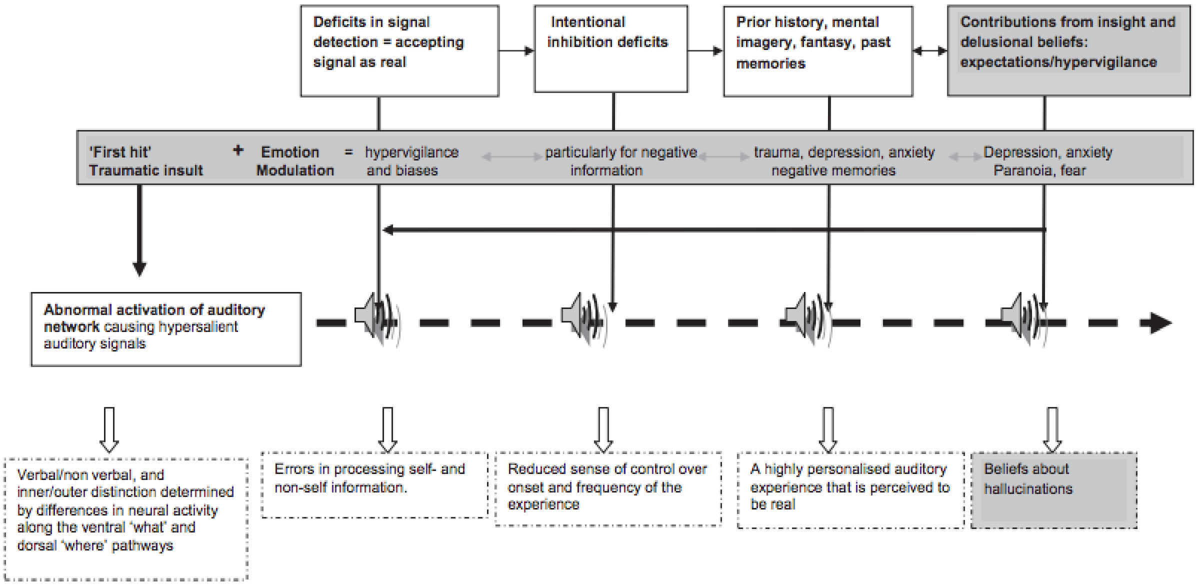

Figure 1. According to this model, AVHs arise from an interaction between (a) an overactivation of neural activities in the auditory areas of the brain and the signals that arise from this and (b) different top-down mechanisms which create a personalized and complex experience. The top-down mechanisms include: (1) errors in processing caused by deficits in signal detection; (2) faulty intentional inhibition that lead to a reduced sense of control over the perceptual experience; (3) expectations, experiences and knowledge which shapes the perceptual experience in a personally relevant way; (4) lack of insight and delusional beliefs contribute to provide a set of beliefs about the AVH; and (5) emotions that impacts on all the aspects of the process and that ensures that there is a bias towards processing emotional material over neutral material. Variations in phenomenological features (bottom row in dotted lines) can be explained using this model, so that individual differences in the extent to which AVH features are present are determined by severity or location of the cognitive deficits. Reprinted from Waters, et al. (2012, p. 689).

and aberrant auditory signals may be influenced by emotional events linked to trauma, dissociations, and other intense negative emotions, leading to an increase in firing rate. The verbal phenomenological properties of AVHs may be accounted for by specific forms of auditory signals (e.g. inner speech or intrusive memories) being more likely to be converted to AVHs (Waters, et al., 2012). Related to this is the fact that it is possible that hallucinating patients are more sensitive to discovering auditory stimuli, as well as more reactive to it, than non-hallucinating patients and controls. Schneider and Wilson (1983) examined this in their study, where schizophrenia patients and non-clinical controls had to respond to frequent and infrequent tones in an auditory perceptual discrimination task. 100 tones were presented to the participants, with 89 “frequent” tones and 11 “infrequent” tones. Their task was to press a button as quickly as possible upon hearing a tone. The schizophrenic patients were split into three groups: those who currently hallucinated, those who had hallucinated before but were currently not hallucinating, and those who had never hallucinated. They found that controls had the fastest reaction times and the most accurate responses compared to all the patient groups, while currently hallucinating individuals had faster reaction times and more accurate responses compared to the other patient groups. This means that currently hallucinating patients and non-clinical controls were the only groups to show a reaction time advantage in the auditory task. It may seem paradoxical that AVHs should be associated with greater accuracy and faster reaction times, but the authors explained this with attentional salience of auditory stimuli associated with hallucinations. To a larger degree than non-hallucinating patients, hallucinating patients may scan their environment for auditory input and are more reactive to it. Similarly with Schneider and Wilson (1983), Vercammen, de Haan, and Aleman (2008) had healthy controls, hallucinating schizophrenic patients and non-hallucinating schizophrenic patients do a speech discrimination task. In the task, subjects had to decide whether a specific spoken word was identical to a previously spoken word embedded in white noise (a heterogeneous mixture of sound waves extending over a wide frequency range such as the noise heard from a radio when it is not tuned to a station). The authors found that controls had a significantly greater ability to distinguish signal from noise when the signal was rendered barely audible by noise, compared to both hallucinating patients and non-hallucinating patients. However, hallucinating patients had a significantly better ability to distinguish signal from noise than non-hallucinating patients. The authors suggest that this may be considered an “attentional prepossession towards perceiving auditory-verbal information, analogous to some extent to the attentional bias for threatening stimuli described in anxiety disorders" (Vercammen, et al., 2008, p. 1182).

Secondly in the Waters model (Waters, et al., 2012), we have the top-down processes. It has been suggested by several studies that aberrant top-down processing could be a cognitive mechanism responsible for self-generated mental events being transformed to AVHs (e.g. Aleman, Böcker, Hijman, de Haan, & Kahn, 2003; Daalman, Verkooijen, Derks, Aleman, & Sommer, 2012; Vercammen & Aleman, 2010). Perception is not just a passive process where an individual perceives everything in an objective way, rather perception is a reconstructive effort (Kveraga, Ghuman, & Bar, 2007). The world is not perceived as it is, but people form a subjective image of it (Behrendt, 1998). In bottom-up processing, information is coming from the external environment via the senses. Concurrently with this, prior knowledge, experiences, goals and needs are shaping this information through top-down processing. What is suggested in the case of hallucinations is that this system of perception is out of balance. Top-down factors are assigned higher priority in determining the final percept at the expense of bottom-up factors, and this might contribute to the genesis of hallucinations (Behrendt, 1998). In sum, according to the model by Waters, et al. (2012) both bottom-up and top-down factors are needed in order for AVHs to emerge.

A model of the neurophysiological basis for the modulation of perceptual processing, where top-down factors "override" bottom-up information, has been proposed. The model, proposed by Grossberg (2000), states that learned top-down sensory expectations can modulate, sensitize, and prime the bottom-up information coming from the senses. Such top-down expectations can be useful on many occasions and help focus attention on expected clusters of sensory features. However, sometimes they can be activated in the absence of bottom-up information, and when this happens, a balance between top-down excitation and inhibition usually prevents them from causing hallucinations. During normal behavioural conditions, the balance is altered to favour top-down excitation due to a volitional signal that is phasically turned on. This, in turn, creates conscious experiences in the absence of external information from the senses, which is a great evolutionary advantage by for example enabling people to engage in internal imagery and speech, as well as planning and other fantasy activities. It is proposed that during mental disorders, like schizophrenia, the phasic volitional signal becomes tonically hyperactive, and top-down expectations can generate conscious experiences that are not under volitional control of the subject, i.e. hallucinations.

Signal Detection Theory

The assumption of Waters, et al. (2012)'s cognitive model that people experiencing hallucinations may present a deficit in signal detection, which produces increased detection of ambiguous or salient signals and increased likelihood of accepting these signals as being real, is based on the Signal Detection Theory (SDT). This theory provides a way to explain how ambiguous stimuli are interpreted by people, by stating that all information recognition takes place in the presence of some uncertainty (Bentall & Slade, 1985). A signal detection task is a common way of testing peoples' interpretation of ambiguous stimuli. In a typical SDT task participants are asked to listen to bursts of white noise and decide whether there was a word present in the noise or not. Sometimes there will be a word present in the noise, while other times a word will not be present. There are thus four possible outcomes in this task. If a word is present, a participant can either correctly state that a word is present (a hit), or she can incorrectly reject the presence of a word (a miss). If a word is not present, the participant can incorrectly claim that there is a word (false alarm), or correctly state that there is no word (correct rejection) (Wickens, 2002). Whether participants report the presence of a word or not is based on the value a decision variable reaches on a signal intensity scale. If the value reaches the participants response criterion he or she will answer that a word was present, but if the value remains below this criterion the participant will answer that a word was not present (Fig. 2*a*).

In the case of hallucinations, the response criterion will shift so that a greater proportion of false alarms occur, while the number of misses will decrease (Fig. 2*b*) (Vercammen, et al., 2008).

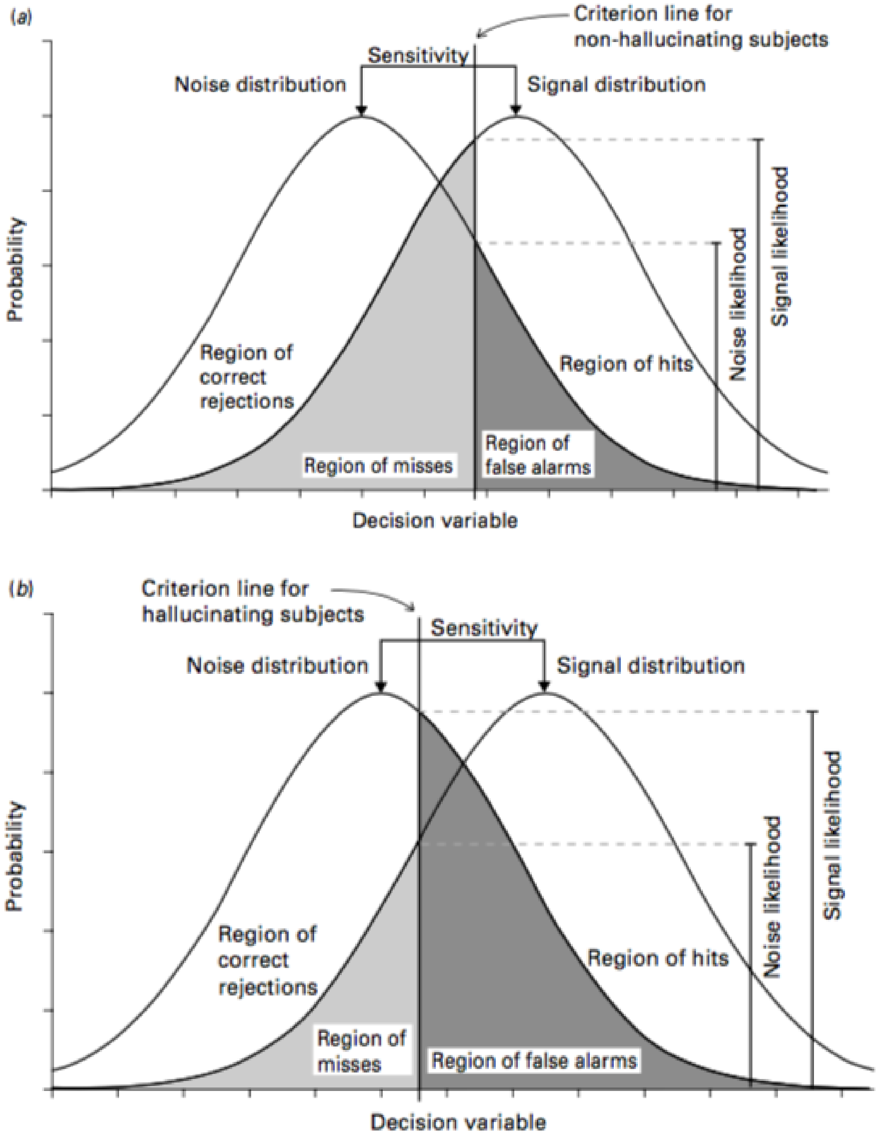

Figure 2. The *x*-axis represents the percepts' vividness. The *y*-axis represents the occurrence frequency of a perceived event. There are two distinct distributions in a signal detection task: a noise distribution, which represents the stimulus' convincingness over all the trials where only noise was presented; and a signal plus noise distribution, which represents the stimulus' convincingness over all the trials where noise and stimulus was presented. The criterion line represents the threshold of the observer for interpreting a stimulus as a real percept. The current figure shows hypothesized thresholds for (*a*) non-hallucinating and (*b*) hallucinating participants. A shift of the criterion to the left results in a larger proportion of false alarms but it also creates an increased probability of determining real occurrences of stimulus (i.e. hits). Reprinted from Vercammen, et al. (2008, p. 1179).

As the occurrence of false alarms during a SDT task reflects the perception of a signal in the absence of concordant external sensory information, false alarms can be thought of as analogous to hallucinations (Hoskin, Hunter, & Woodruff, 2014). This makes SDT tasks useful tools in the study of hallucinations. In addition to this, SDT tasks allow perceptual performance to be understood in terms of both sensitivity, which is the ability to distinguish signal from noise and detect “true” signals, and response bias, which is the willingness to detect signals in uncertain conditions. In the context of hallucinations, false alarms can occur through a change towards a more liberal response bias, i.e. a higher tendency to report a signal (Hoskin, et al., 2014).

The SDT task was initially developed by Bentall and Slade (1985) to investigate perceptual judgments of hallucinating people. They wanted to apply the SDT task to investigating hallucinations and look at whether hallucinations result from judgment errors or whether they result from vivid auditory imagery. To test this, the authors compared the performance on a SDT task for participants scoring highest and lowest on the Launay-Slade Hallucination Scale (LSHS), a questionnaire developed to assess hallucination proneness in non-clinical populations. The SDT task consisted of 50 5 seconds noise trials and 50 5 seconds signal and noise trials. In the signal and noise trials, the word “who” was presented 3 seconds after the onset of the white noise. The results showed that participants with a higher proneness to hallucination were more willing to report the presence of a stimulus in the white noise compared to participants with lower proneness to hallucinate. There was no difference between participants scoring high and low in hallucination proneness for perceptual sensitivity. This suggests that hallucinations are not an impairment of perception, but rather arise from an impairment of judgment (Bentall & Slade, 1985).

Since the initial study by Bentall and Slade (1985) several studies using different versions of the SDT task have found that patients with hallucinations and hallucination-prone individuals from the non-clinical population, relative to controls without a psychiatric disorder and with a low hallucination proneness, have a significantly lower response bias. However, they do not differ in sensitivity (Alganami, Varese, Wagstaff, & Bentall, 2017; Barkus, et al., 2007; Bentall & Slade, 1985; Daalman, et al., 2012; Vercammen & Aleman, 2010). For example, in the study by Vercammen and Aleman (2010) the authors wanted to do a two-phase study to test whether hallucinations are due to an over-reliance on top-down factors. In the first phase, participants were screened using the LSHS, while in the second phase, participants with high and low hallucination proneness were presented with sentences where the last word (target word) was masked by white noise or where the last word had been replaced by white noise. In half of the trials where the word was masked by white noise, the target word was highly predictable given the sentence context (e.g. the sailor sells his *boat*), while in the other half of the trials the target word was unpredictable (e.g. the sailor sells his *chair*). The authors were interested in the top-down errors, which was scored when the participant responded with the predictable word given the sentence context, but the target word was an unpredictable word or just white noise without a word. The results showed that an increase in top-down errors was related to an increase in hallucination proneness. This indicates that the influence of expectation is stronger in those who have a high hallucination proneness versus those who have a low proneness. Consequently, aberrant top-down processing, especially in the form of strong semantic expectation, may be a contributing factor to the experience of AVHs. In a study by Alganami, et al. (2017) they tested for the extent to which different suggestion instructions affects performance on a SDT task in participants with a high and low hallucination proneness, as well as explored the relationships between suggestibility as a trait, defined as “an individual’s susceptibility or responsiveness to suggestion” (Carhart-Harris et al., 2015, p. 785), dissociation, defined as “a disruption of and/or discontinuity in the normal, subjective integration of one or more aspects of psychological functioning” (Spiegel et al., 2011, p. E19), and hallucination proneness. The experimenters conducted two experiments. Participants in both experiments performed measures of hallucination proneness (LSHS), trait suggestibility, and dissociation, and participants in the upper and lower tertiles of LSHS scores performed an auditory SDT task. Suggestions were made prior to the task related to the number of expected targets. In experiment 1, there were two suggestibility conditions, one condition with high suggestion (told that voices would be present 80% of occasions) and one condition with low suggestion (told that voices present 30% of occasions). In experiment 2, there were three conditions, one with no suggestion (told that voices would be present on some occasions), one with high suggestion (told that voices would be present 70% of occasions), and one with no voice suggestion (told that no voice would be present). Results showed that trait suggestibility and dissociation are highly correlated with each other, as well as both being predictors of hallucination proneness after controlling for paranoia. Furthermore, highly hallucination-prone participants had a significantly lower response bias in both experiments. The bias scores of both highly hallucination-prone and low hallucination-prone were significantly influenced by suggestions equally in experiment 1, while in experiment 2, highly hallucination-prone participants were more reactive to the high suggestion condition than the low hallucination-prone controls, showing that judgments of whether a signal is present or absent are sensitive to suggestions. There was no significant effect of neither suggestion nor hallucination proneness on sensitivity. Contrary to these findings, some studies have found that patients with hallucinations and hallucination-prone individuals do not have a significantly lower response bias compared to non-patient or low hallucination proneness controls (Crowe et al., 2011; Hoskin, et al., 2014; Moseley, Smailes, Ellison, & Fernyhough, 2016). Hoskin, et al. (2014) examined the effects of stress and semantic expectation on the performance of non-clinical participants on a SDT task. The task consisted of sentences where the last word in the sentence (target word) either was masked by white noise, in order to make it difficult to hear, or it was replaced by white noise. By manipulating the content of the sentences there was either a high or a low semantic expectation of the target word. For example, “The apple fell from the *tree*” was designed to induce a high expectation of the word ´tree´. “The person looked at the *tree*” was, however, designed to induce a low expectation of the word ´tree´. The study found that semantic expectation had a significant effect on sensitivity, with the sensitivity increasing with higher presence of expectation. Expectation also had a significant effect on response bias, with a higher bias value when expectation was present. Stress did not have a significant effect on neither sensitivity nor response bias. However, it was found that trait anxiety predicted the effect of stress on response bias, such that, when under stress, anxious participants had a greater shift towards reporting a signal. Contrary to a significant amount of past research, measures of positive schizotypy (LSHS and Schizotypal Personality Questionnaire (SPQ)) were not found to significantly predict response bias in the study. A possible explanation for this given by the authors, is that previous studies have contrasted groups of participants specifically recruited for their very high or very low schizotypy scores. Possibly, the relationship between SDT task performance and positive schizotypy is not linear, and only for those with extreme scores are differences in performance noticeable. However, another study (Li, Yang, Chen, Chen, & Liu, 2003), employing high and low schizotypy groups also failed to show a relationship between positive schizotypy and SDT task performance. Thus, there is a need for research to identify more details about the relationship between hallucination proneness in non-clinical individuals and SDT task performance.

Merckelbach and van de Ven (2001) explored the cognitive underpinnings of the white noise effect (i.e. hearing signals in the white noise in a SDT task that are not present) by having participants perform a version of the SDT task, as well as complete self-report measures of mental imagery ability, defined as “representations and the accompanying experience of sensory information without a direct external stimulus” (Pearson, Naselaris, Holmes, &

Kosslyn, 2015, p. 590), social desirability, which refers to a heightened sensitivity to comply with the experimenters' expectations (Merckelbach & van de Ven, 2001, p. 138), fantasy proneness, defined as "a deep, profound, and long-standing involvement in fantasy and imagination" (Lynn, Rhue, & Sarason, 1986, p. 35), and hallucination proneness. They suggested that perhaps false alarms in a SDT task does not reflect a tendency to hallucinate, but a general tendency to be deeply involved in ones' fantasies, a tendency to comply with the experimenters' expectations, or simply a vivid mental imagery. The authors found no relationship between false alarms in the SDT task and mental imagery, confirming earlier findings by Bentall and Slade (1985), or between false alarms and social desirability. However, hallucination proneness and fantasy proneness were both found to be related to false alarms. A follow-up logistic regression suggested that fantasy proneness had a more substantial contribution to the false alarms than hallucination proneness. Merckelbach and van de Ven (2001) claims that this is an important finding as it implies that false alarms in SDT tasks does not reflect the presence of hallucinatory experiences in a large portion of the general population, but rather reflects the tendency of people to endorse odd items. However, the authors also showed that fantasy proneness and hallucination proneness were highly correlated ($r = .56$). It is thus possible that the lack of prediction of hallucination proneness reflects a statistical artefact, that is the shared variance between the two variables would have led to the exclusion of one of them in the statistical model used by the authors). Similarly, Crowe, et al. (2011) wanted to investigate the effect of stress and caffeine on the expression of schizophrenia symptoms in non-clinical participants. Based on self-report, the participants were either assigned to a high or low stress condition, and a high or low caffeine condition. They then performed a version of the SDT task. Based on the findings by Merckelbach and van de Ven (2001) the study also measured fantasy proneness, mental imagery ability, and social desirability as these factors may be implicated with an individual's proneness to hallucinate.

Fantasy proneness, mental imagery ability, and social desirability all had non-significant correlations with false alarms in the SDT task, but more surprising was the fact that the authors did not find a correlation between hallucination proneness and false alarms. However, they did find a significant correlation between fantasy proneness and hallucination proneness, as measured by the LSHS. Crowe, et al. (2011) concludes that this indicates that the hallucination proneness measure does not directly measure hallucination proneness but is instead related to peoples' tendency to fantasize. In another study, Belayachi, Laloyaux, Larøi, and Van der Linden (2015) examined the relationship between encoding style and schizotypy. Encoding style is the tendency to process information quickly based on pre-existing schemata (Lewicki, 2005), for example believing, for a very brief moment, that a leaf along the roadside is a squirrel. It is indicated by research that high levels of internal encoding lead to an increased probability of interpreting cues from the environment in terms of pre-existing (internal) schemata. The authors found that there was a significant association between internal encoding style and positive symptoms of schizotypy (cognitive-perceptual and disorganization dimensions). Additionally, internal encoding of perception leads people, according to encoding style theory, to strongly feel that they are seeing or hearing things that are not there (Lewicki, 2005), indicating a strong influence of top-down processes on perception. Belayachi, et al. (2015) reasoned that extreme internal encoding could lead to immediate subjective experiences similar to what one would experience for the actual presentation of the same things, which provides a possible explanation for why distorted perception is experienced as real in individuals with schizotypal symptoms. Related to this is the aberrant salience hypothesis by Kapur (2003). According to this hypothesis, positive psychotic symptoms reflect an impaired mechanism where unusual or incorrect significance, importance, or salience is assigned to ambiguous stimuli. The idea is that dopamine is a key factor in mediating the salience of environmental events and internal representations, and excessive dopaminergic transmission in people with schizophrenic symptoms results in abnormal salience of internal representations, leading to a distorted perception and interpretation of the external reality (Belayachi, et al., 2015).

While most studies have focused on the influence of top-down processes on hallucinatory reports, none have explored the influence of bottom-up processes. Considering that the model of auditory hallucinations (Waters, et al., 2012) claims that hallucinations arise from aberrant signals caused by hyperactivation in the auditory cortex, the lack of exploration of the bottom-up processes is problematic. It can be hypothesized that the auditory cortex is overwhelmed by white noise during a SDT task because it receives a lot of potentially significant information. In trying to understand what is happening, the cortex triggers aberrant signals resulting in false alarms, because the information it receives looks like a signal. However, the human hearing is not equally sensitive to all the frequencies making up the white noise. Both humans and animals use sounds to communicate, but humans are the only members of the animal kingdom that can use articulate speech. For humans, speech is the main way of communication, and as a result of this they are not equally sensitive to all frequencies. Rather they are most sensitive to the frequency range covered by human speech, most likely due to natural selection (Rossing, 2014). This means that people are more sensitive to some of the frequencies making up the white noise than others. It is thus possible to hypothesize that the hyperactivation of auditory cortex is due to specific frequencies composing the white noise (i.e. those relating to human speech) and not others. This is particularly relevant as people usually report hearing voices in the noise. Even though most studies using the SDT paradigm use white noise, it has never been clearly stated why white noise was chosen in these tasks, and indeed one study (Moseley, et al., 2016) used pink noise. The hypothesis therefore seems particularly relevant regarding the fact that the reason why white noise (instead of another type of noise) was chosen in SDT tasks is unclear. There is thus a need for assessing the specific role played by the noise on the perception of false alarms during a SDT task.

Aims and Predictions

The goal of the present project was to gain a better understanding of the specific cognitive mechanisms underpinning hallucinatory reports in SDT tasks, by looking at the impact of top-down and bottom-up processes. Thus, the goal is twofold, where the aims are (1) to compare two modified versions of white noise, where one is made up of frequencies relating to the human language (Bergen noise) and one is made up frequencies not relating to the human language (Voss noise) on their effect on response bias in high and low hallucination-prone participants (bottom-up), and (2) to investigate the effect of different levels of semantic expectation on response bias on a SDT task for participants high and low in hallucination proneness (top-down).

To investigate our aims, we designed an auditory SDT task where predictive signaling were manipulated by varying the level of semantic expectation in sentences where the last word in the sentence were either masked or replaced by noise. The semantic content of the sentences either strongly suggested the identity of the target word, or it did not. The noise was manipulated by using the two different types of noise (i.e. Bergen and Voss noise).

Findings relating to SDT task performance, response bias and sensitivity have varied across studies but tend to show that high hallucination-prone participants have a significantly lower response bias but no significant difference for sensitivity, compared to low hallucination-prone participants. Based on this it was predicted that people with high hallucination proneness would have a significantly lower response bias compared to people with low hallucination proneness. However, the sensitivity would not be significantly different between the two groups (hypothesis 1). If predictive top-down signals are potential factors in AVH, it could be expected that predictive signaling will lead to a more liberal response bias in a SDT task for those prone to hallucinate. Additionally, one could expect participants to have a higher sensitivity when there is a high semantic expectation based on the findings by Hoskin, et al. (2014) and

Vercammen and Aleman (2010). Thus, a lower response bias and a higher sensitivity was predicted in the SDT task when there was a high semantic expectation compared to a low semantic sentence frame. The effect on response bias, but not on sensitivity, was predicted to be larger for participants with high hallucination proneness scores relative to low hallucination-prone participants (hypothesis 2). Human hearing is more sensitive to the frequencies making up the human speech. One can assume that it is these frequencies that affect hallucinatory reports in SDT tasks using white noise, and not all the frequencies in the white noise. Participants were therefore predicted to have a lower response bias in Bergen noise-trials relative to trials with the Voss noise, and this effect would be more pronounced in highly hallucination-prone participants compared to participants with low hallucination proneness (hypothesis 3). Moreover, it could be expected that participants will have a higher sensitivity in Voss noise as the most important frequencies relating to the human language have been removed from this noise, thereby making it easier for participants to differentiate between the noise and a spoken word. It was therefore predicted that participants will have a higher sensitivity in Voss noise compared to Bergen noise (hypothesis 4). Furthermore, a significant interaction between noise, semantic expectation and group was predicted, with a significantly lower response bias among participants in Bergen noise compared to Voss noise, and this effect would be larger in the high semantic expectation condition among participants with high hallucination proneness (hypothesis 5). Different cognitive mechanisms, such as fantasy proneness, encoding style, aberrant salience, and suggestibility may be implicated in false alarms. This is something that have not been properly investigated, and the hypothesis is therefore exploratory (hypothesis 6).

Method

Participants

A two-phase design was used in the current study. Phase 1 involved the recruitment of 285 students from the University of Bergen by handing out screening questionnaires during lecture breaks and contacting them directly at the university campus (e.g. cafeteria, library etc.). They were screened using a modified version of the Launay-Slade Hallucination Scale (LSHS) (Larøi & Van der Linden, 2005), as well as demographic questions (age, sex and education level). Participants were excluded from the study if they were either under the age of 18 or above the age of 30, their native language was not Norwegian, they had a hearing impairment, or if they had a current or previous psychiatric or neurological disorder. Participants were then selected for phase 2 of the study based on the presence or absence of auditory hallucinations. Thus, the 23 participants (13 females, 10 males, mean age 20.87 years, *SD* = 2.03) with a score of 3 or 4 on at least two of the four AVH-items of the LSHS, and the 20 participants (14 females, 6 males, mean age 22.5 years, *SD* = 2.39) with a total score between 0 and 2 on the four AVH-items were asked to take part in the second experimental phase of the study. People with an extreme lower total score on the LSHS were excluded in order to avoid nay-saying response bias, that is when participants choose to deny or not endorse any of the questionnaire items (Heal & Sigelman, 1995). There was no difference between the high and low hallucination proneness groups for gender distribution χ^2 (1, n = 43) = .36, p = .55. However, there was a significant difference for age between the high (*M* = 20.87, *SD* = 2.03) and low (*M* = 22.5, *SD* = 2.39; t (41) = 2.42, p = .02, two-tailed) hallucination proneness groups. There was a significant difference between high and low hallucination-prone participants for the LSHS total score, t (24.49) = -9.79, p < .001, and for the LSHS auditory factor score, t (26.04) = -17.82, p < .001. For the purpose of obtaining valuable data, the precise objectives of the study were hidden from the participants, who were only told that it was a study of auditory perception, semantic processing and personality traits. This was done to ensure the validity of the study by avoiding selection bias, i.e. if participants knew the study was looking at hallucinations they might have avoided reporting hallucinations, or they might have special interests in hallucinatory experiences and reported experiences they do not really have. Participants received a monetary compensation of 150 NOK for partaking in both phases of the study.

Test Material

Participants were evaluated with an auditory semantic SDT task and different questionnaires.

Semantic signal detection task. The task required participants to listen to bursts of noise and decide whether a word was present in the noise or not. Both the noise and the semantic expectation of the sentences preceding the noise were manipulated.

The current semantic signal detection task is an adaption of the task used in Hoskin, et al. (2014). The task consisted of 140 short emotionally neutral sentences of 3-9 words, where half of the sentences were spoken by a female voice, while half were spoken by a male voice. For each sentence, the target word (i.e. the last word in the sentence) was either replaced by a 2000 millisecond (ms) burst of Voss noise or Bergen noise, or it was masked by one of the two noises for 2000 ms to change its audibility. Participants were presented with two different types of sentences designed to create a high level or a low level of sematic expectation regarding the target word. For example, the sentence "It is fun to *read*" is an example of a low semantic expectation sentence, while the sentence "She drinks water when she is *thirsty*" is an example of a high semantic expectation sentence.

Out of the 140 sentences, 70 had a high semantic expectation frame, while 70 had a low semantic expectation frame. Each of these two conditions were again split into two conditions, with 35 sentences with Voss noise and 35 sentences with Bergen noise in each. Since the focus of this study is on false alarms, a word was present in the noise for 15 of the 35 sentences, while it was absent for 20 of the sentences. The different conditions were all matched in number of words and they were all pseudo-randomized in presentation. For the 15 sentences with the presence of a word in the noise, 10 had a signal-to-noise ratio (SNR) level that rendered them barely audible, and 5 had a SNR level that rendered them difficult to hear, but clearer than those that were barely audible. The target word was presented randomly in the noise to make it impossible for participants to predict.

Thus, there were four types of sentences in the final edition of the semantic signal detection task. An example is:

1) Semantic expectation word + noise: The sailor sells his **BOAT**
2) Semantic expectation only noise: The sailor sells his ****
3) No sematic expectation word + noise: The sailor talks to his **UNCLE**
4) No semantic expectation only noise: The sailor talks to his ****

Before the task started, participants were instructed that they would be listening to sentences spoken by a male or female, and that the last word would either be hidden by noise or completely replaced by noise. Furthermore, they were told that the audibility of the word might vary from trial to trial, and in some cases be very difficult to hear. Lastly, participants were instructed that their task was to decide whether the last word was present or not for each sentence.

The experimental paradigm was presented on a computer via the experiment software E-Prime 2.0. The auditory stimuli were presented through the Beyerdynamic DT880 headphones, connected to the laptop via a DragonFly Black v1.5 USB. Each trial in the SDT task began with a visual countdown in order to focus the participants´ attention on the task. The visual countdown consisted of three circles of different sizes presented in descending order, each circle was presented on the screen for 850 ms. Following this, the sentence frame (either high or low expectation) was presented verbally through the headphones together with a fixation cross on the screen. Each sentence frame was between 1500 ms and 3500 ms in duration. Next, the participant either listened to the target word masked by Voss noise, the target word masked by Bergen noise, only Voss noise with no target word present, or only Bergen noise with no target word present. Immediately after this, a sentence was presented on the computer screen asking the participant to indicate whether he or she had heard a word in the noise by using the keys C and N on the keyboard. When a response was made, participants were prompted to respond how certain they were that they had indeed heard a word on a 4-point Likert scale with the anchors 1 (uncertain) and 4 (certain). Before starting the real task, each participant did three practice trials with the option of repeating the practice trial if they felt the task was unclear.

The data was processed using SDT. First, the yes/no scale data were converted into hit and false alarm rates. It is yes/no data because the task involved signal trials, where a signal was present, and noise trials, where only noise and no signal was present. After each trial, the participant was asked to indicate whether a signal was present with yes or no. Secondly, two measures were calculated according to the procedure for yes/no tasks, described by Stanislaw and Todorov (1999): response bias (β) and sensitivity ($d´$). β was chosen as a measure of response bias to be consistent with previous studies relating hallucinating proneness and performance on auditory SDT tasks (e.g. Varese, Barkus, & Bentall, 2011; Vercammen, et al., 2008) which in a recent meta-analysis showed robust links to hallucination proneness (Brookwell, Bentall, & Varese, 2013). For β, a value of 1 indicates that there is no bias towards responding neither yes nor no. If the β-value is greater than 1 this signifies a bias towards responding no, while values less than 1 signifies a bias towards making yes-responses A d´ value of 0 indicates that the participant is unable to distinguish signals from noise, whereas more positive values indicate a greater ability to detect signals. $+\infty$ is the highest possible value of d´ and represents perfect performance (Stanislaw & Todorov, 1999).

Construction of the sentences. A total of 164 sentences were created for the SDT task. Of the 164 sentences, 82 were designed to have a high semantic expectation frame, while 82 had a low semantic expectation frame. A pre-test was conducted with an unrelated sample of participants to ensure that the high semantic expectation-sentences allowed for predicting the target word, while the low semantic expectation sentences did not allow for predicting the target word. The sentences were presented to 20 individuals (12 females, 8 males, mean age 27 years, SD = 9.12), with the target word removed. Sentences were randomized in presentation. Participants were asked to complete the sentences with the first word that came to mind. Sentences where at least 80% of participants had responded with the same word were regarded as high semantic expectation sentences, while sentences where no more than 35% of participants had responded with the same word were regarded as low semantic expectation sentences. Based on this, 140 sentences were selected out of the 164, with 70 in each semantic expectation group.

The sentences and target words were recorded separately in order to keep a neutral prosody of each word. They were recorded using Audacity and then edited using Adobe Audition to remove any interference. All recordings were normalized.

Construction of Bergen noise and Voss noise. For the present study, two different noises were created to either replace or mask the last word of the sentences during the SDT task. The aim was to create a noise containing the language-related frequencies (Bergen noise) and another noise without these frequencies (Voss noise).

Bergen noise is a modified version of the white noise, and it is based on formant frequencies, which are the specific sound frequencies related to the perception of human language. The formants are the specific tones and groups of tones that give the different speech sounds their character and timbre (Store Norske Leksikon [SNL], 2009), with the first two formants (F1 and F2) being the most important for understanding language, and F0 being the fundamental frequency. To make this noise, the formant frequencies from Hillenbrand, Getty, Clark, and Wheeler (1995) were used. An average value was calculated for the formants F0, F1, and F2 and combining males and females. White noise was then generated using Adobe Audition, and the formant frequencies were boosted in this noise using the FFT filter effect.

The Voss noise was created as being the opposite noise of Bergen noise. In particular, the averaged formant frequencies for F0, F1, and F2 that were used to create the Bergen noise, were removed using the FFT filter effect in order to create the Voss noise. This ensured no overlap between this noise and the Bergen noise, and leaves Voss noise with few frequencies relating to human language.

Both noises were normalized to have the same intensity. Following this, the last word of 60 sentences were embedded in either Bergen or Voss noise, leading to 60 sentences with a word in the noise and 80 sentences with only noise. The words were embedded in the noise using Adobe Audition. To set the SNRs in the task, a pilot study was conducted with 10 participants. Here, participants were asked to listen to a continuous burst of white noise with several words imbedded in it at different SNRs. Four words were presented at each SNR level. Participants were instructed to raise their hand when they heard something in the noise (they did not need to know what the word was). For the present experiment, two different SNRs were defined, one that renders the word barely audible and one that renders it difficult to hear but clearer than the other SNR. This was done in order to increase the level of expectation of a last word completing each sentence. The first SNR was based on the findings where around 60% of participants identified two of the four words at a specific SNR level, while the second SNR was based on the findings where 90% of participants heard all four words at a specific SNR level.

Questionnaires

Screening phase:

Launay-Slade Hallucination Scale (LSHS). LSHS measures participants' tendency to hallucinate or have hallucination-like experiences within sleep-related hallucinations, daydreaming, intrusive or vivid thoughts, auditory hallucinations and visual hallucinations. The current experiment used a modified version (Larøi & Van der Linden, 2005) of the original by Launay and Slade (1981). A Norwegian version translated by Kråkvik et al. (2015) was used. It is a 16-item scale where participants rate the items on a 5-point Likert-type scale from 0 (certainly does not apply to me) to 4 (certainly applies to me). In addition, the following item "I have heard people calling my name and found that nobody has done so" was added from a revised version of the LSHS by McCarthy-Jones and Fernyhough (2011) to increase the number of AVH-items. As this questionnaire was part of the screening phase, the items from the LSHS were hidden in 10 more general questions assessing auditory perception, quality of sleep, and personality traits, to render the aim of the scale less obvious. The total score ranges from 0 to 68, where higher scores indicate increased proneness to hallucinate. For the subscales the score ranges from 0 to 16 for sleep-related hallucinations and for auditory hallucinations, 0 to 12 for daydreaming and for intrusive or vivid thoughts, and 0 to 8 for visual hallucinations. The scale has an excellent internal consistency with a Cronbach alpha coefficient of .909.

Experimental phase:

After completing the SDT task, participants were asked to complete several questionnaires.

The Creative Experiences Questionnaire (CEQ). The CEQ (Merckelbach, Horselenberg, & Muris, 2001) is a measure of fantasy proneness. It is a 25-item questionnaire with "yes-or-no"-response options. The scale was translated to Norwegian using the back translations procedure. The Cronbach alpha coefficient was .847.

Encoding Style Questionnaire (ESQ). ESQ (Lewicki, 2005) assesses the tendency to process information more or less quickly based on pre-existing schemata versus environmental cues. It is a 21-item questionnaire where six items measure encoding style, while the remaining 15 items are filler items. Responses are registered on a 6-point Likert-type scale with anchors 1 (strongly disagree) and 6 (strongly agree), with the total score ranging from 6 to 36. The scale was translated to Norwegian using the back translations procedure. It has a good internal consistency with a Cronbach alpha coefficient of .779.

Aberrant Salience Inventory (ASI). ASI (Cicero, Kerns, & McCarthy, 2010) is a 29-item scale that measures incorrect or unusual assignment of salience, significance, or importance to otherwise innocuous stimuli. Responses are registered as “yes-or-no”-answers. The questionnaire consists of five factors: feelings of increased significance, senses sharpening, impending understanding, heightened emotionality, and heightened cognition. The first factor, increased significance, represents increased attribution of significance to stimuli. The second factor, senses sharpening, can be described as sensory flooding or sensory gaiting. The third factor, impending understanding, is composed of items reflecting a general feeling of importance or significance, which often accompany a psychotic episode. The fourth scale, heightened emotionality, is related to the increased levels of anxiety present when an individual tries to understand the increased importance of stimuli during the early stages of a psychotic episode. The fifth and final factor, heightened cognition, reflects experiences where individuals feel as though they are part of something important that is not readily apparent. The scale was translated to Norwegian using the back translations procedure. The Cronbach alpha coefficient for the scale was .828.

The Cardiff Anomalous Perceptions Scale (CAPS). CAPS (Bell, Halligan, & Ellis, 2006) is a 32-item questionnaire that measures distress, intrusiveness, and frequency of perceptual anomalies, such as hallucinations. The items are presented as “yes-or-no” questions. If a “yes” response is given, participants must rate the item for distress, intrusiveness, and frequency on a 5-point Likert scale from 1 (distress: not at all distressing; intrusiveness: not at all distracting; frequency: happens hardly at all) to 5 (distress: very distressing; intrusiveness: completely intrusive; frequency: happens all the time). The scale was translated to Norwegian by colleagues at the faculty for another study currently underway. For the present study, the total score of the factor "clinical psychosis" was used, as well as the total score for the auditory items. The total score for clinical psychosis ranges from 0 to 4, while it ranges from 0 to 7 for the auditory items. For the clinical psychosis factor, the Cronbach alpha coefficient was .594 which is good considering the factor only consists of four items. The Cronbach alpha coefficient for the seven auditory items was .771.

Short Suggestibility Scale (SSS). The Short-Suggestibility Scale (SSS) is a shorter adaption of the original 95-item Multidimensional Iowa Suggestibility Scale (MISS; Kotov, Bellman, & Watson, 2004) The questionnaire consists of 21-items rated on a 5-point Likert-type scale from 1 (strongly disagree) to 5 (strongly agree). The SSS investigate suggestibility, a personality trait that reflects a general tendency to accept messages and be influenced by the environment. The minimum total score is 21, while the maximum score is 105. The scale was translated to Norwegian using the back translations procedure. The Cronbach alpha coefficient was .645.

Procedure

The experiment took place in a sound proof room. Before the experimental task was presented, standard audiograms were obtained for each participant to ensure satisfactory auditory perception. Participants then completed the SDT task before responding to the questionnaires. Lastly, participants were debriefed and asked to sign the consent form.

Ethics

An application was sent and approved by the regional committee for medical and health research ethics (REK) (see Appendix A). Necessary ethical information was given in the two consent forms. The first consent form was given to participants during the first phase of the study in order to be able to use their screening results. However, as participants were initially not told that the study looked at hallucinations (to avoid compromising the studies validity), a second consent form was given at the end of the study, after participants had been fully debriefed. Every participant was given an individual code and only the code was used to identify data material. The consent forms were the only forms to contain the participants' names, and contact information (which was their telephone number) was associated with the participants' code only. All forms and questionnaires were stored separately in a locked closet, in a locked office. The scrambling-key (name-code list) was stored on a secure server belonging to UIB: SAFE (Sikker Adgang til Forskningsdata og E-infrastruktur), which is a server specifically designed to store such sensitive data. The anonymous computerized results were stored at a password protected external hard drive, which was stored in a locked closet, in a locked office.

Results

Signal Detection Task

Response bias. A 2x2x2 factorial repeated measure analysis of variance (ANOVA) was conducted to assess the impact of the two different semantic expectation conditions (high semantic expectation versus low semantic expectation), and the two different types of noises (Bergen noise versus Voss noise) on participants' β-scores, across high and low hallucination-prone groups. The results are presented in Table 1.

Table 1.

A 2x2x2 factorial repeated measure ANOVA which investigates the impact of two different semantic expectation conditions (high semantic expectation versus low semantic expectation), and two different types of noises (Bergen noise versus Voss noise) on participants' β-scores, across high and low hallucination-prone groups.

Variable	Wilks' Lambda	Hypothesis *df*	Error *df*	*F*	Partial η^2
Expectation	.96	1	41	1.72	.04
Expectation*group	.96	1	41	1.69	.04
Noise	.63	1	41	24.08***	.37
Noise*group	.93	1	41	2.93	.07
Noise*Expectation	.99	1	41	.56	.01
Noise*group*expectation	.95	1	41	2.21	.05
Group	-	1	41	1.46	.03

*** $p < .001$

There was no significant main effect of expectation on the *β*-score. However, there was a substantial main effect of noise, with a lower *β*-score in the Voss noise compared to the Bergen noise. The main effect comparing the two groups (high and low hallucination proneness) was not significant (fig. 3).

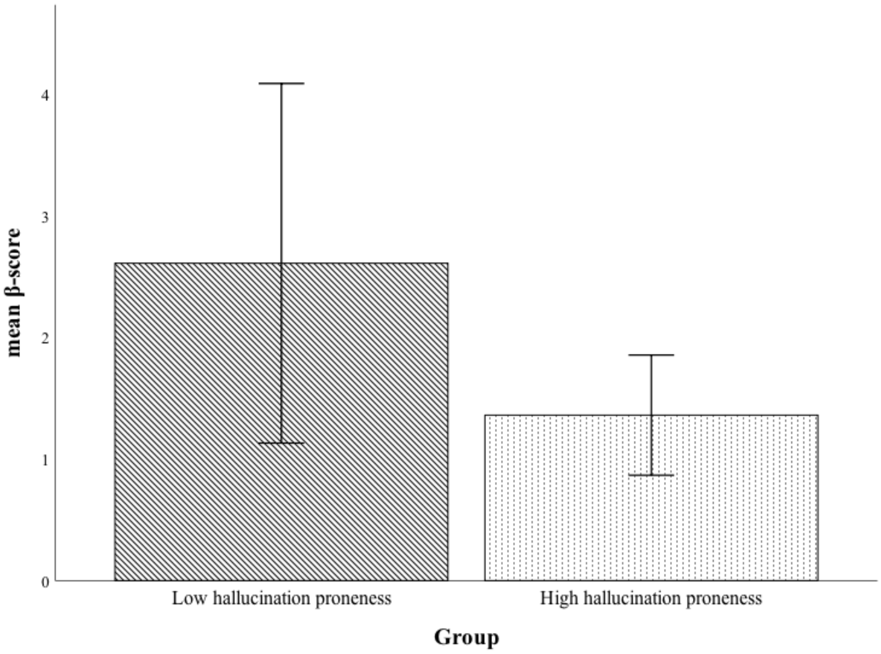

Figure 3. Mean *β*-scores for high and low hallucination-prone participants.

There was no significant interaction between semantic expectation condition and group on the β-score. There was a trend level interaction between type of noise and group on the β-score, $p = .095$. Planned contrasts were conducted to examine the group differences in the Bergen noise and in the Voss noise. The contrasts showed that participants in the high hallucination proneness group had a lower β-score in the Bergen noise condition than the low hallucination proneness group, at a trend level, t (22.51) = 1.85, $p = .078$, $d = .58$, but that differences in the β-score between the two groups in the Voss noise condition did not reach statistical significance, t (41) = .34, $p = .734$, $d = .10$ (fig. 4). Planned contrasts were also done to investigate the difference between Voss and Bergen noise in the high hallucination proneness group and in the low hallucination-proneness group. They revealed that high hallucination-prone participants had a lower β-score in the Voss noise compared to the Bergen noise, t (22) = -2.6, $p = .016$, $d = .46$. They also showed that low hallucination-prone participants had a lower β-score in Voss noise than in Bergen noise, t (19) = -2.7, $p = .014$, $d = .70$ (fig. 4).

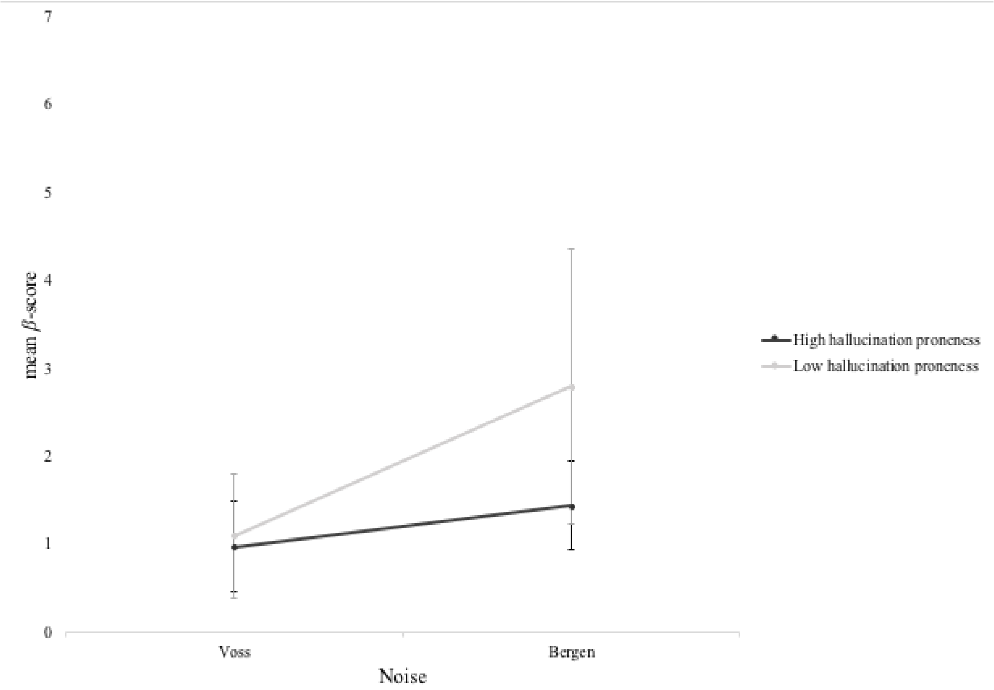

Figure 4. Mean β-scores for high and low hallucination-prone participants in the Voss noise and the Bergen noise.

Results (ANOVA, table 1) revealed no significant interaction between the type of noise and the level of semantic expectation on the *β*-score. The interaction between the type of noise, the level of semantic expectation and group on the *β*-score was also non-significant. As a specific hypothesis was made in regard to this, planned contrasts were conducted despite the lack of significant effect to examine the group difference for the high semantic expectation and Bergen noise condition and for the low semantic expectation and Bergen noise condition. Results showed that participants in the high hallucination-prone group had a significantly lower *β*-score compared to participants in the low hallucination-prone group in the high semantic expectation and Bergen noise condition, t (23.06) = 2.43, p = .023, d = .76. However, there was no significant group difference for the low semantic expectation and Bergen noise condition, t (41) = .38, p = .704, d = .12. In addition, planned contrasts were done to examine the difference between the high semantic expectation and Bergen noise condition and the low semantic expectation and Bergen noise condition in the high hallucination proneness group and in the low hallucination proneness group. The results showed that with Bergen noise, the high hallucination-prone participants had a significantly lower *β*-score when there was a high level of semantic expectation than when there was a low level of semantic expectation, t (22) = 2.34, p = .029, d = .56. There was no significant difference between high and low semantic expectation for the low hallucination-prone participants in Bergen noise, t (19) = -.31, p = .76, d = .07 (fig. 5). Repeating the above planned contrasts with Voss noise instead of Bergen noise were all non-significant, t (41) = -.03; t (41) = .28; t (22) = -.11; t (19) = -.46, all ps ≥ .649 (fig. 6).

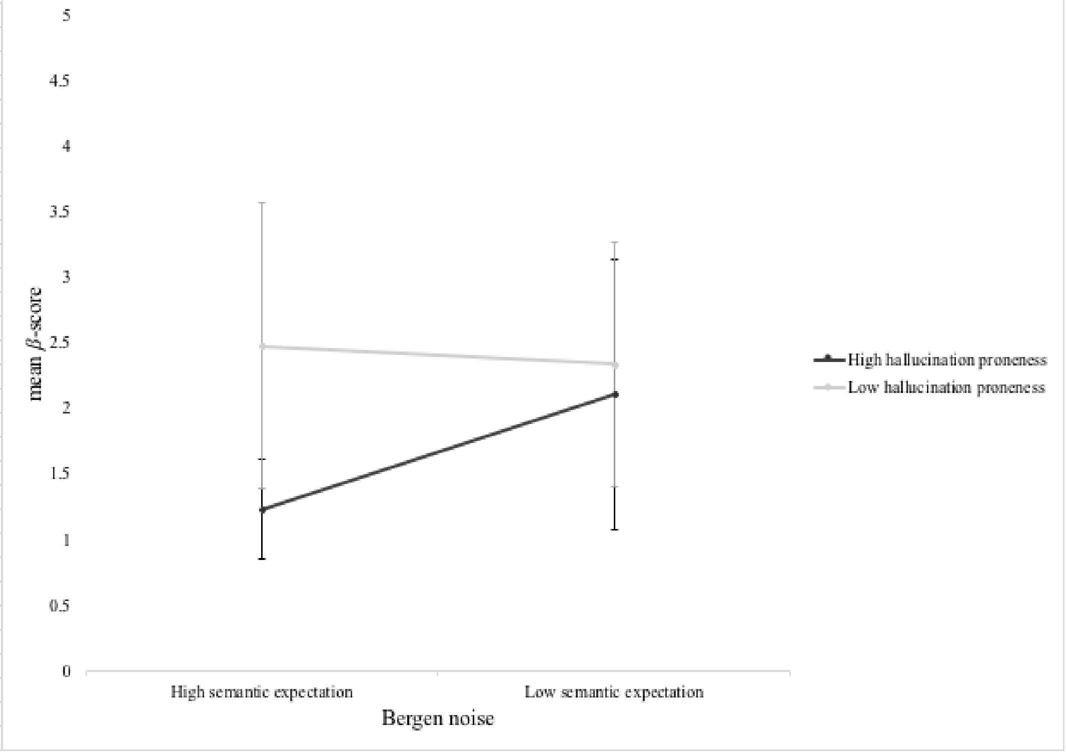

Figure 5. Mean β-scores for high and low hallucination-prone participants in high and low semantic expectation in the Bergen noise.

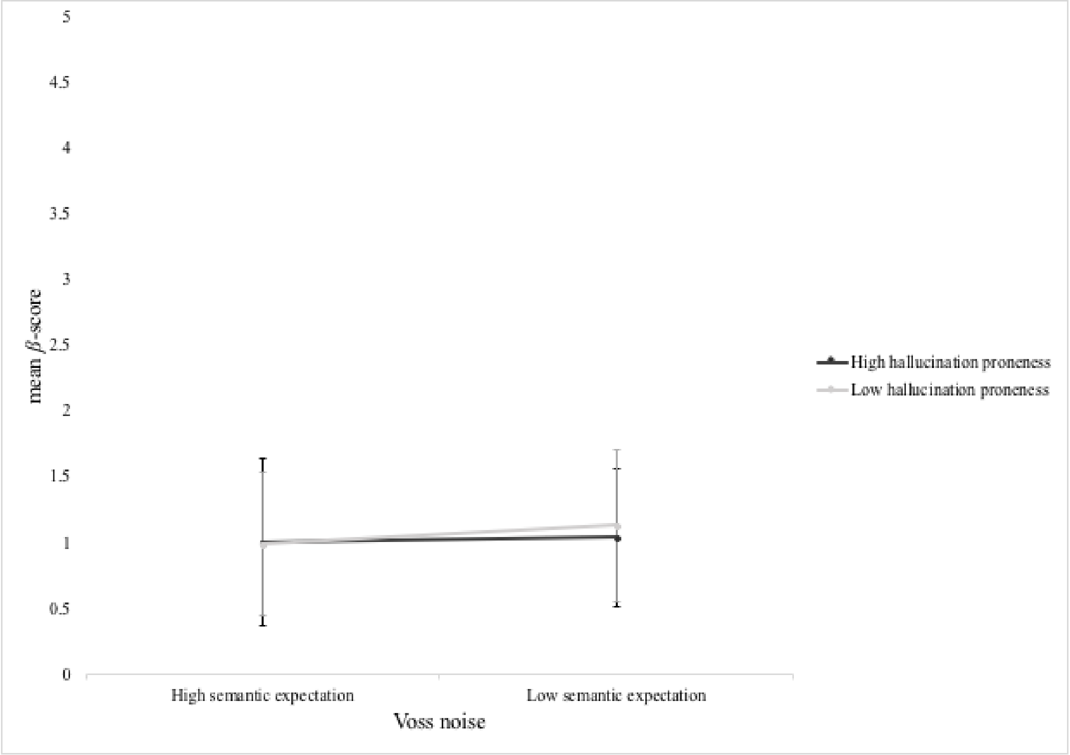

Figure 6. Mean β-scores for high and low hallucination-prone participants in high and low semantic expectation in the Voss noise.

Sensitivity. A 2x2x2 factorial repeated measure ANOVA was conducted to assess the impact of the two different semantic expectation conditions and the two different types of noises on participants' *d´*-scores, across high and low hallucination-prone groups. The results are presented in Table 2.

Table 2.

A 2x2x2 factorial repeated measure ANOVA which investigates the impact of two different semantic expectation conditions (high semantic expectation versus low semantic expectation), and two different types of noises (Bergen noise versus Voss noise) on participants' d´-scores, across high and low hallucination-prone groups.

Variable	Wilks' Lambda	Hypothesis *df*	Error *df*	*F*	Partial η^2
Expectation	.98	1	41	.89	.02
Expectation*group	.93	1	41	3.20	.07
Noise	.16	1	41	219.39***	.84
Noise*group	.99	1	41	.26	.01
Noise*expectation	.65	1	41	22.24***	.35
Noise*expectation*group	.98	1	41	.84	.02
Group	-	1	41	4.08*	.09

* $p < .05$, *** $p < .001$

There was no main effect of expectation on the *d´*-score. However, there was a substantial main effect of noise, with a higher *d´*-score in the Voss noise compared to the Bergen noise. The main effect comparing the two groups (high and low hallucination proneness) was significant, suggesting that there is a difference in sensitivity between high and low hallucination-prone participants, with low hallucination-prone participants having a higher sensitivity than high hallucination-prone participants (fig. 7).

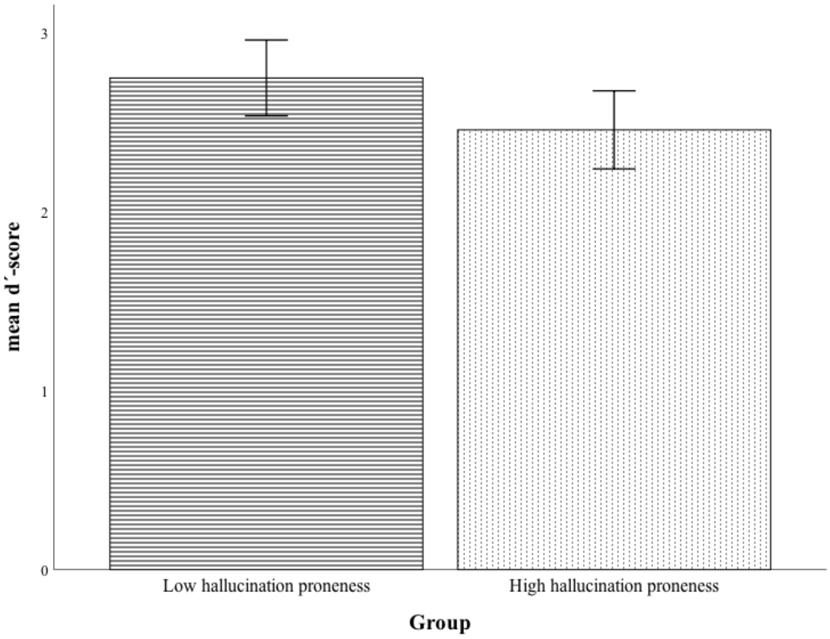

Figure 7. Mean *d´*-scores for high and low hallucination-prone participants.

There was a trend level interaction between the level of semantic expectation and group on the *d´*-score, *p* = .081. Planned contrasts were conducted to examine the group difference with a high level of semantic expectation and with a low level of semantic expectation. The results revealed that participants in the low hallucination proneness group had a significantly higher *d´*-score than the high hallucination proneness group in the high semantic expectation condition, *t* (41) = 2.81, *p* = .008, *d* = 1.13, but that differences in *d´*-score between the two groups in the low semantic expectation condition did not reach statistical significance, *t* (41) = .81, *p* = .426, *d* = .25. In addition, planned contrasts were conducted to investigate the difference between the high and low level of semantic expectation for the high hallucination proneness group and for the low hallucination proneness group. The contrasts showed that there was a non-significant difference for the *d´*-score between the high and low semantic expectation conditions for the low hallucination proneness group, *t* (19) = .93, *p* = .365, *d* = .25, nor did the difference between the high and low semantic expectation conditions for the high hallucination proneness group reach statistical significance, *t* (22) = -1.55, *p* = .136, *d* = .27 (fig. 8).

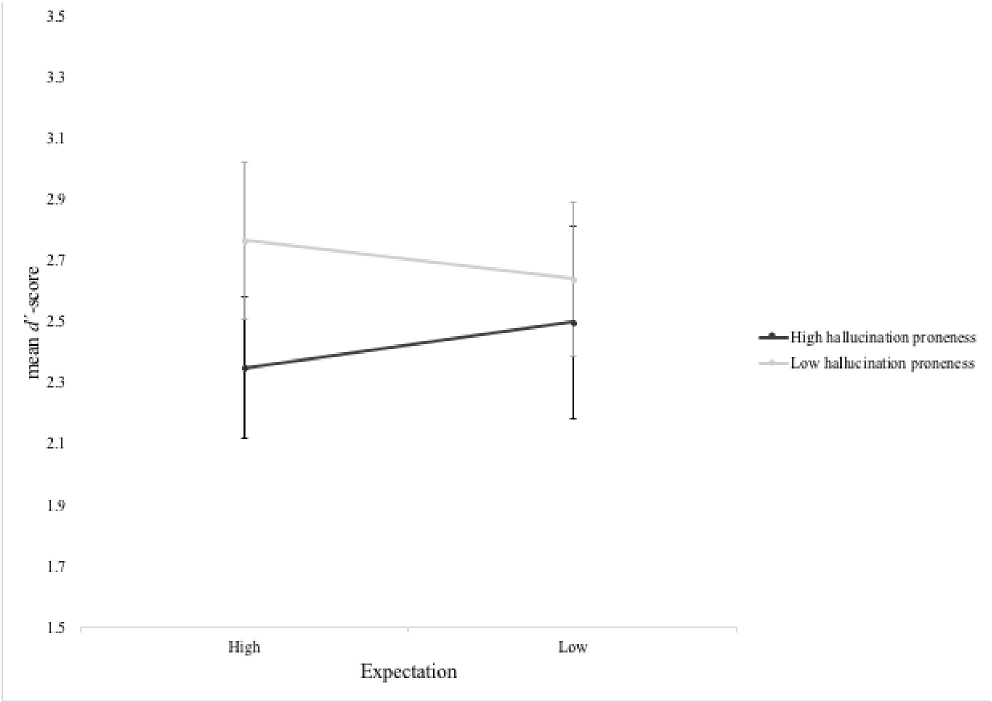

Figure 8. Mean *d´*-scores for high and low hallucination-prone participants in high and low semantic expectation.

There was no significant interaction between the type of noise and group on the *d´*-score. However, there was a significant interaction between the type of noise and the level of semantic expectation on the *d´*-score. To examine the difference between the two levels of semantic expectation in Voss noise and in Bergen noise, planned contrasts were conducted. They revealed that participants had a significantly higher *d´*-score in Voss noise when there was a high level of semantic expectation than when there was a low level of semantic expectation, t (42) = -4.25, $p < .001$, $d = .51$. They also showed that participants had a significantly higher *d´*-score in Bergen noise when there was a low level of semantic expectation compared to a high level of semantic expectation, t (42) = -2.26, $p = .029$, $d = .41$. The interaction between noise, expectation and group was non-significant.

T-Tests.

Independent-samples t-tests were conducted to compare the ASI score, ESQ score, CEQ score, CAPS clinical psychosis score, CAPS auditory items score, and SSS score between high and low hallucination-prone participants. The results are presented in Table 3. There was a significant difference for all scores between high and low hallucination proneness groups, except for SSS scores where there was no significant difference in scores for participants with high and low hallucination proneness.

Table 3.

Independent-samples t-tests for hallucination proneness group and ASI scores, ESQ scores, CEQ scores, CAPS clinical psychosis scores, CAPS auditory items scores, and SSS scores.

Variable	High hallucination proneness		Low hallucination proneness		
	M	*SD*	*M*	*SD*	*t*-test
ASI score	15.48	4.79	9.90	4.80	-3.81***
ESQ score	23.91	5.33	18.20	5.37	-3.49***
CEQ score	10.39	5.21	4.70	2.45	-4.68***
CAPS clinical psychosis score	1.96	1.30	.35	.59	-5.35***
CAPS auditory items score	3.26	1.91	.65	.88	-5.88***
SSS score	54.58	11.45	51.90	9.78	-.79

*** p < .001 (2-tailed). *N* = 43.

Correlational Analyses.

The relationship between the β-score in the high semantic expectation and Bergen noise condition, and other cognitive measures (LSHS total score, LSHS auditory factor score, ASI score, ESQ score, CEQ score, CAPS clinical psychosis score, and CAPS auditory items score) were investigated using Pearson product-moment correlation coefficient. The reason why the high semantic expectation and Bergen noise condition was used, was due to the fact that participants in the high hallucination-prone group had a significantly lower β-score compared to participants in the low hallucination-prone group in this condition. This suggests a necessity for both these factors to be present for hallucinatory experiences to emerge. As the independent-samples t-test had shown SSS scores to not be significantly different between the high and low hallucination-prone groups, this variable was excluded from the correlational analysis. Correlations between variables are all presented in Table 4. Higher levels of LSHS total score, LSHS auditory factor score, ASI score, ESQ score, and CAPS auditory items score were all significantly correlated with a lower β-score in the high semantic expectation and Bergen noise condition. CEQ score and CAPS clinical psychosis score were not significantly correlated with the β-score in this condition.

Table 4.

Pearson product-moment correlations between β-scores in Bergen noise in the high semantic expectation condition and measures of hallucination proneness, aberrant salience, encoding style, fantasy proneness, and anomalous perceptual experience.

Variables	Total LSHS	LSHS auditory factor	Total ASI	Total ESQ	Total CEQ	CAPS clinical psychosis	CAPS auditory items
β-scores in Bergen noise and high semantic expectation condition	-.31*	-.30*	-.30*	-.39**	-.23	-.28	-.33*

* $p < .05$ (2-tailed), ** $p < .01$ (2-tailed), $N = 43$

Discussion

The aim of the current study was to explore the cognitive mechanisms underpinning false alarms and hits in a SDT task by looking at the impact of top-down and bottom-up processes. In particular, the present study aimed at exploring the main and interaction effect of the type of noise used in a SDT task (either containing language related frequencies or not, respectively Bergen noise and Voss noise) and the level of semantic expectation (high versus low) on response bias and sensitivity in high and low hallucination-prone individuals. Another aim was to investigate the relations between the response bias observed during the SDT task and hallucination proneness and several other cognitive processes, such as fantasy proneness, encoding style, aberrant salience, and suggestibility. There are both theoretical and practical reasons for using the SDT paradigm. It has with some success been used to examine hallucination proneness in a number of previous studies (e.g. Alganami, et al., 2017; Barkus, et al., 2007; Bentall & Slade, 1985; Hoskin, et al., 2014; Vercammen & Aleman, 2010), and it allows for objective measuring, as well as creating artificial conditions of ambiguity, where the level of ambiguity can be manipulated.

Response Bias

The results showed that there was no main effect of group on response bias, that is the high and low hallucination-prone participants did not differ in regard to their response bias. This is in contrast with what was hypothesised, as well as with findings from many previous studies (e.g. Alganami, et al., 2017; Barkus, et al., 2007; Bentall & Slade, 1985). However, the results can be viewed as in accordance with findings made by Hoskin, et al. (2014) and Crowe, et al. (2011), who found that positive schizotypy (LSHS and SPQ) did not significantly predict response bias, and that the correlation between hallucination proneness and false alarms was non-significant, respectively.

Contrary to what was predicted in the second hypothesis, no main effect of semantic expectation was found for response bias, that is the participants' response biases were approximately the same whether the level of semantic expectation was high or low. This finding can be viewed in contrast to findings by Hoskin, et al. (2014), who found that expectation had a significant effect on response bias, with a higher bias value when a high level of expectation was present. Additionally, the interaction effect between expectation and group for response bias was not statistically significant. This is not in line with previous findings by Vercammen and Aleman (2010), who showed that the influence of expectation on false alarms in a SDT task is stronger in those who have a high hallucination proneness versus those who have a low proneness, indicating an over-reliance on top-down factors in these participants. The current findings indicate that predictive top-down signals alone are not sufficient in eliciting false alarms in a SDT task in hallucination-prone participants.

The present study showed a main effect of noise on response bias, with participants having a lower response bias in the Voss noise than in the Bergen noise. However, if we look more closely at the numbers we discover that the lower response bias in the Voss noise compared to the Bergen noise is due to participants not having a response bias in the Voss noise (β =1.04), while in the Bergen noise they have a large bias towards saying no to the presence of a word in the noise (β=2.04). The lower response bias in the Voss noise could be due to the fact that it is easier to distinguish noise from words in this noise, which results in participants not having a bias. Moreover, the Voss noise is much less likely to trigger false alarms than the Bergen noise due to the absence of language frequencies. When Bergen noise is present, participants may get confused about what is happening (i.e. whether a word is present in the noise or not) because the auditory cortex receives a lot of potentially significant information from the noise. The presence of language frequencies in the noise makes the information the cortex receives look like signals, causing the cortex to trigger aberrant signals when it tries to make sense of all the information. The consequence of the aberrant signals is a larger bias. Furthermore, there was a trend level interaction effect between noise and group for response bias. Data analyses showed that both participants in the high and low hallucination proneness groups had a lower response bias in the Voss noise compared to the Bergen noise. In the Bergen noise, high hallucination-prone participants had a lower response bias compared to low hallucination-prone participants, at a trend level. This might indicate that the high hallucination proneness group is more affected by the effect of the Bergen noise than what the low hallucination proneness groups is. Meaning that the language related Bergen noise most likely cause an increase in false alarms. An increase in false alarms will affect the bias in the direction of saying yes to the presence of a word (i.e. $\beta < 1$), and the lower response bias in the high hallucination proneness group compared to the low hallucination proneness group points to the fact that this increase is more likely to happen with these participants than with low hallucination-prone participants.

The interaction effect of noise and expectation for response bias was not statistically significant. This indicates that noise and expectation are not sufficient in eliciting false alarms in a SDT task. Possibly, the effect of hallucination proneness group is also needed. That is, a certain type of noise and a certain level of semantic expectation may elicit false alarms only in a certain group of people (high hallucination-prone participants).

Results showed that the interaction effect between noise, semantic expectation and group for response bias was not statistically significant. Nevertheless, when the interaction was explored in more detail with planned comparisons, it was discovered that participants in the high hallucination proneness group had a lower response bias than participants in the low hallucination proneness group when there was a combination of a high level of semantic expectation and the Bergen noise. Additionally, high hallucination-prone participants had a lower response bias when there was a high level of semantic expectation and Bergen noise compared to a low level of semantic expectation and Bergen noise, indicating that the Bergen noise itself is not sufficient in eliciting false alarms. Rather, an interaction between the Bergen noise and a high level of semantic expectation is needed for a more liberal response bias to occur. Furthermore, in the Voss noise there was no significant difference between the groups and/or the two levels of semantic expectation, further indicating the necessity of the interaction between the Bergen noise and a high level of semantic expectation.

In terms of the signal detection theory, the lower response bias among participants with a high hallucination proneness compared to participants with low hallucination proneness can be explained by an increase in false alarms made during the presentation of the ambiguous stimuli. The results illustrate a deficit in signal detection in high hallucination-prone participants when stimuli are made ambiguous by the Bergen noise and a high level of semantic expectation. This is a deficit that does not seem to be present for low hallucination-prone participants. Furthermore, going back to the model of Waters, et al. (2012), the findings seem to be in line with the idea postulated by this model, namely that both bottom-up and top-down processes are needed to elicit auditory hallucinatory experiences, represented here by the Bergen noise and high semantic expectation. To put it more clearly, AVHs arise from the signals generated from an interaction between an overactivation of neural activities in the auditory areas of the brain, caused by the Bergen noise, and a high level semantic expectation, which increases the probability of the signal being accepted as real and decreases the likelihood of the signal being inhibited. As previously explained, the Bergen noise consists of the main frequencies relating to the human language, thus presenting the auditory cortex of the participants with a lot of information that could be potential signals. In trying to understand all this potentially significant information, the cortex becomes overactivated and triggers aberrant signals. When this is combined with the decreased likelihood of the signal being inhibited caused by the high level of semantic expectation, the result seems to be the elicitation of auditory hallucinatory experiences.

The group difference in the Bergen noise and low semantic expectation condition did not reach statistical significance. Neither did the comparison between the Bergen noise and high semantic expectation condition and the Bergen noise and low semantic expectation condition for low hallucination-prone participants. These results show that there is a specific effect of the combination of a certain type of noise and a certain type of semantic expectation, and it can thus, at least partially, explain why previous studies have shown varying findings for response bias when using a SDT task.

Sensitivity

Concerning sensitivity, there was a main effect of group, with low hallucination-prone participants having better sensitivity than high hallucination-prone participants. This finding is contrary to what was hypothesised, but nevertheless in accordance with some previous studies (Ishigaki & Tanno, 1999; Vercammen, et al., 2008). Vercammen, et al. (2008) explains the lower sensitivity on a speech discrimination task by schizophrenia patients with and without auditory hallucinations compared to a healthy control group, with the number of cognitive problems that characterize schizophrenia, such as working memory deficits, distractibility and perseveration. The lower sensitivity among high hallucination-prone participants found in the current study may point to similar cognitive problems as those characterizing schizophrenia being associated with high hallucination proneness as well. This adds support to the continuum hypothesis, which states that the psychosis phenotype is expressed at levels below its clinical manifestation and exists on a continuum with normal functioning (van Os, et al., 2009).

Contrary to what was hypothesised, no main effect of semantic expectation was found for sensitivity. This can also be contrasted to findings by Hoskin, et al. (2014), who found semantic expectation to have a significant effect on sensitivity, with higher sensitivity when there was a high level of semantic expectation. There was a trend level interaction effect between expectation and group for sensitivity. The data revealed that in the high semantic expectation condition, low hallucination-prone participants had better sensitivity than high hallucination prone participants. In the low semantic expectation condition there was no difference between the groups. This shows that the difference in sensitivity between the groups is primarily driven by the effect of high semantic expectation. Possibly, the low hallucination-prone participants were aided by the high expectancy in deciding whether a word was present or not, while participants with high hallucination proneness did not have any effect of the high level of semantic expectancy. Rather, the high semantic expectancy might create confusion for the high hallucination-prone participants, making them uncertain whether they really heard something or whether they just thought it because the preceding sentence created a high expectancy for that word.

There was a large effect of noise on sensitivity. As hypothesised, participants had better sensitivity in the Voss noise than in the Bergen noise, most likely because the main frequencies relating to the human language were not present, thereby making it easier for participants to differentiate between the noise and a spoken word. It makes sense that it is easier to differentiate between noise and signal when language related frequencies are absent from the noise, while the signal is a spoken word containing language frequencies, compared to when language related frequencies are present in the noise and the signal is a spoken word containing language frequencies. While there is a large overlap in frequencies between the noise and the signal in the latter, there is only a small overlap between the noise and the signal in the former. Furthermore, there was not a significant interaction effect between noise and group for sensitivity, suggesting that the effect of the Voss noise on sensitivity is the same in both high and low hallucination-prone participants.

The results revealed that there was a significant interaction between noise and semantic expectation for sensitivity. Analyses showed that in the Voss noise, participants had a higher sensitivity when there was a high level of expectation than when there was a low level of expectation. In the Bergen noise, on the other hand, participants had higher sensitivity when there was a low level of expectation compared to a high level of expectation. Most likely this is because when a certain type of noise (Bergen) and a certain level of semantic expectation (high) are present, participants will be confused about what is happening, resulting in worse sensitivity. It has already been discussed how the presence of high semantic expectation results in lower sensitivity for high hallucination-prone participants compared to low hallucination-prone participants, and that this may be due to the confusion created by the high level of semantic expectancy of the sentence preceding the word in the SDT task. It has also been discussed how participants have a poorer sensitivity in the Bergen noise than in the Voss noise because the main frequencies relating to the human language are present in this noise, making it more difficult to differentiate between the noise and a word. Thus, when the confusion created by the high semantic expectancy is combined with the difficulty of differentiating between the noise and the signal in the Bergen noise, one can expect a decrease in sensitivity.

The interaction between noise, semantic expectation and group for sensitivity was not statistically significant. This indicates that the decrease in sensitivity caused by the combination of a high semantic expectancy and the Bergen noise is not affected by group, that is the decrease in sensitivity caused by this combination is approximately the same in both high and low hallucination-prone participants. Since the interaction effect was non-significant, no planned comparisons were not executed, as there was not a specific hypothesis on this interaction.

Cognitive Correlates of Response Bias

Another aim was to look at whether the false alarms reported by participants were related to hallucination proneness or to some other cognitive mechanism. To begin with, group comparison analyses revealed a significant difference between the high and low hallucination proneness groups for questionnaires measuring fantasy proneness (CEQ), aberrant salience (ASI), encoding style (ESQ), auditory perceptual anomalies (CAPS auditory items) and clinical psychosis (CAPS clinical psychosis), with the high hallucination proneness group having a higher score than the low hallucination proneness group on all questionnaires. No significant difference was found for suggestibility (SSS) between the two groups, and this questionnaire was therefore excluded from further analyses. Hallucination proneness, auditory hallucination proneness, aberrant salience, encoding style, and auditory perceptual anomalies all had medium correlation effects with total response bias, where higher questionnaire scores were associated with lower response bias. Fantasy proneness and clinical psychosis both had non-significant correlation effects with response bias. These findings indicate that a lower response bias is related to hallucination proneness, but also to some other related cognitive mechanisms such as an internal encoding style and aberrant salience. It does, however, not seem to be related to fantasy proneness. The negative, medium correlation between encoding style and response bias indicate support for findings by Belayachi, et al. (2015), who also found a significant association between internal encoding style and positive symptoms of schizotypy. Internal encoding can lead to an increased probability of interpreting cues from the environment in terms of pre-existing schemata, so when participants are presented with sentences that creates a high level of expectation of what the succeeding target word is, they most likely interpret the cues (i.e. the language related Bergen noise) in terms of the pre-existing schemata created by the high expectancy sentence. This leads to an increase in the numbers of false alarms and, consequently, a lower response bias, adding support to the reasoning by Belayachi, et al. (2015) that internal encoding could lead to similar subjective experiences as those one would have for the actual presentation of the same things. However, caution should be made with this interpretation as a lower response bias does not necessarily mean that participants have a bias towards saying yes to the presence of a word in the noise, and it does not necessarily mean that they have more false alarms. A bias score of 1 means that the participant has no response bias, while a score below 1 means that the participant has a response bias towards saying that a word is present, and a score above 1 means that the participant has a response bias towards saying that a word is not present. A lower response bias could simply mean that they have no bias compared to other participants who have a bias towards saying that a word is not present. Moreover, the correlational findings for ASI can be argued to support the aberrant salience hypothesis by Kapur (2003), which states that ambiguous stimuli is assigned unusual or incorrect significance, importance, or salience due to an impaired cognitive mechanism. The abnormal salience of internal representations leads to distorted perception and interpretation of external reality. If this hypothesis is applied to the current study, it can be argued that the ambiguous noise stimuli in the SDT task were assigned incorrect salience, particularly the language related Bergen noise, causing distorted perceptions, increased false alarms and a lower response bias. According to Kapur (2003) the key factor in mediating the salience of environmental events and internal representations is dopaminergic transmission and the excess of this in people with schizophrenic symptoms. The current findings can be interpreted as an indication of excessive dopaminergic transmission in high hallucination-prone people, but this is something that needs to be investigated further in future studies. As with encoding style, caution should be made with the interpretation. The non-significant correlation between fantasy proneness and response bias does not support previous findings by Merckelbach and van de Ven (2001) that false alarms in SDT tasks reflect peoples tendency to endorse odd items, and not the presence of hallucinatory experiences. Rather, it is in line with findings by Crowe, et al. (2011), who found fantasy proneness not to be significantly correlated with false alarms.

Implications

The present study showed that a combination of the Bergen noise and a high level of semantic expectation resulted in a lower response bias among high hallucination-prone participants, compared to low hallucination-prone participants. The study also showed that false alarms were related to hallucination proneness, but also to some other related cognitive mechanisms such as an internal encoding style and aberrant salience. These results have many implications for both clinical practice and for research. Concerning research, the implication that auditory hallucinations emerge through an interaction between bottom-up and top-down processes can help further research in other relevant modalities (e.g. the visual modality), as well as with a clinical participant sample. Additionally, the findings suggest that white noise is not the most efficient noise in eliciting false alarms. Instead, the new language related type of noise, Bergen noise, is more useful in SDT tasks when the aim is to elicit false alarms. Future studies that make use of the SDT task should therefore put the Bergen noise into use instead of the now commonly used white noise. Furthermore, the present study gives more weight to a line of research that has presented varying findings, by indicating that there is a specific effect of noise and of semantic expectation on response bias, and it can thus partially explain the previous varying results on this topic. Gaining new theoretical knowledge about a common and debilitating psychiatric symptom such as AVH is greatly beneficial to both affected individuals and the society at large, as it has enormous financial and emotional costs.

Concerning clinical practice, there is a need for more direct and less biased tools to measure hallucinations. Having hallucinations is perceived negatively by society and is often stigmatized. Consequently, people may not always want to report that they have hallucinations due to this stigma. Moreover, questionnaires and interview-based assessments are biased by the fact that the person needs to identify experiences as being hallucinations and remember them. A task like the one presented in this study might be useful in the development of new clinical tools to assess and identify hallucination proneness, for example for teenagers in the prodromal stage. It offers objective measuring of hallucination proneness, independent of introspection and self-assessment, and it creates artificial conditions of ambiguity where the level of ambiguity can be manipulated.

Limitations and Future Directions

A number of limitations can be identified in the study. Firstly, there was a significant difference between the high and low hallucination proneness groups for age and it can be argued that this has had an impact on the results. However, it is important to underline that the difference was quite small (22.5 versus 20.87 years). In addition, correlational analyses showed that age was not significantly correlated with the total β-score, r = -28, n = 43, p = .066. The d'-score, on the other hand, was significantly correlated with age, r = .33, n = 43, p = .033, with younger participants having a lower sensitivity. However, controlling for age (ANCOVA) did not change the original results, suggesting that age did not have an impact on them. Secondly, the formant frequencies used to make the Bergen noise were English and not Norwegian formant frequencies. Our sample of participants, however, were all native Norwegian speakers. Possibly, the Norwegian speaking participants were not as sensitive to a noise made up of English formant frequencies as they would be for a noise made up of Norwegian formant frequencies. However, the difference in frequencies between the two languages are deemed to be small (Iverson & Evans, 2007) and, additionally, most Norwegian students are highly familiar with the English language. It is therefore reasonable to believe that they have a certain degree of sensitivity for English formant frequencies even though it is not their native language. Thirdly, as put forward by other studies on the white noise paradigm (Barkus, et al., 2007), the question of whether the phenomenology of the hallucinatory experiences obtained in the current study are analogous to those found in psychotic disorders, remains open. While schizophrenia is characterized by spontaneous experiences of complex voice hearing, the hallucinatory experiences elicited in the current experiment are false perceptions of single words, obtained in a context of constructed expectations and during artificial conditions of ambiguity. It is hard to see the latter experience as identical to the former. Fourthly, the sample size in the current study was relatively small, and it is possible that a larger sample size would have yielded different results. In particular, the small sample size means that the study was only able to detect large effects, and the smaller effects did perhaps not reach significance-level, or they might have been missed entirely. A good example of an effect that might have been statistically significant given a larger sample size is the triple interaction effect on response bias. For while the interaction effect was non-significant, the planned comparisons showed several significant effects. Lastly, university students are unlikely to be representative of the population at large, and it is therefore unclear how the current results would relate to the general population.

In this study, testing was done of several possible cognitive mechanisms (i.e. hallucination proneness, fantasy proneness, encoding style, aberrant salience and suggestibility) underpinning false alarms during conditions of ambiguity. However, future studies should look into further exploring other possible underpinning variables and their relationship with false alarms and response bias. For example, hallucination proneness has been demonstrated to be related to many cognitive mechanisms that may also have an impact on performance on the SDT task. In particular, a recent meta-analysis (Pilton, Varese, Berry, & Bucci, 2015) showed that hallucinations were highly correlated with dissociation, that is, the tendency to be detached from the immediate surrounding, to be “on autopilot”. In a related way, Shin et al. (2015) found that positive psychotic symptoms were related to mind-wandering, that is a tendency to experience unrelated thoughts during a task. Both dissociation and mind wandering reveal a tendency to be disconnected from the external world, which may have an impact on performance on the SDT task, as people would not pay sufficiently attention to the task and interpret ambiguous stimuli as being real perceptions. Another future direction should be to look at whether the influence of top-down and bottom-up processes extends into other modalities than the auditory one, that is whether the top-down and bottom-up influence represents a more general cognitive bias or if this processing abnormality is specifically linked to the auditory sensory system. A few studies have already looked at the visual modality. For example, Aleman, et al. (2003) looked at the auditory and visual modalities through multiple behavioural measures of auditory and visual mental imagery and perception, as well as a measure of reality monitoring. They compared performance between schizophrenia patients with and without hallucinations and control subjects. For the visual modality there was no differences on any of the mental imagery measures, nor on the reality monitoring measure, indicating that visual hallucinations are not associated with distortions in mental imagery. Similarly, Böcker, Hijman, Kahn, and De Haan (2000) investigated mental imagery and perception in the auditory and visual modalities in hallucinating and nonhallucinating patients. Consistent with Aleman, et al. (2003), they observed no differences between the groups. They did, however, observe a stronger influence of mental imagery on perception in the auditory compared to the visual modality in patients with auditory hallucinations. That is, in the hallucinating group, detection of a stimulus was enhanced to a larger extent in an auditory task than in an analogue visual task when the subjects had imagined that stimulus beforehand. These studies suggest that the influence of top-down and bottom-up processes does not extend into the visual modality, however, more studies looking at both the visual and other modalities are needed. As the current study was conducted on healthy participants from the general population, a natural next step would be to do a similar study with a psychotic sample. It is important to investigate whether the current results are representative for a psychotic population, especially in relation to possible clinical implications and the development of clinical tools. According to Badcock and Hugdahl (2012) researchers should take a more critical viewpoint of the continuum model of AVH. One cannot assume that findings from non-clinical samples will be replicated in clinical populations, and there is a need to be cautious in assuming that results from a non-clinical population can help our understanding of AVH in schizophrenia and other clinical populations. The next step should therefore be to try to replicate the current findings in a clinical sample.

Conclusion

Using a SDT task and participants with high and low hallucination proneness, this study offers support for the model of AVH by Waters, et al. (2012). According to this model, auditory hallucinations emerge through an interaction between bottom-up and top-down processes. The current study suggests that false alarms arise from an interaction between the signals that are generated from an overactivation of neural activities in the auditory areas of the brain, caused by the Bergen noise, and a high level of semantic expectation, which increases the probability of the signal being accepted as real and decreases the likelihood of the signal being inhibited. The reason why the Bergen noise causes this overactivation of neural activities is probably due to the presence of language frequencies in the noise. This is further supported by the fact that the difference in response bias is not present in the Voss noise, where the language frequencies are absent. If Bergen noise was replaced with Voss noise, or high semantic expectation with low semantic expectation, the response bias difference was no longer present. This suggests that a certain type of noise and a certain type of expectation are needed for the emergence of false alarms in high hallucination-prone individuals. In addition, the present study showed that a lower response bias was related to hallucination proneness, but also to other related cognitive mechanisms such as an internal encoding style and aberrant salience. However, contrary to some previous studies, the current study does not offer support for the implication of fantasy proneness in the emergence of false alarms.

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Appendix A – Approval by REK

REK
REGIONALE KOMITEER FOR MEDISINSK OG HELSEFAGLIG FORSKNINGSETIKK

Region:	**Saksbehandler:**	**Telefon:**	**Vår dato:**	**Vår referanse:**
REK vest	Camilla Gjerstad	55978499	14.02.2018	2017/2490/REK vest
			Deres dato:	
			06.02.2018	

Vår referanse må oppgis ved alle henvendelser

Julien Laloyaux
Biological and medical psychology

2017/2490 Forhold mellom auditorisk persepsjon og personlighetstrekk

Forskningsansvarlig: Universitetet i Bergen
Prosjektleder: Julien Laloyaux

Vi viser til søknad om forhåndsgodkjenning av ovennevnte forskningsprosjekt. Søknaden ble behandlet av leder av Regional komité for medisinsk og helsefaglig forskningsetikk (REK vest) ipå fullmakt. Vurderingen er gjort med hjemmel i helseforskningsloven (hfl.) § 10.

Prosjektomtale

Man tror at personer som opplever hallusinasjoner har vanskeligheter med skille mellom ekte persepsjoner og støy, som kan føre til falske persepsjoner. Dette kan måles ved hjelp av en oppgave der deltakere skal oppdage ord skjult i støy. Studien har som mål å bedre forstå hvordan slike falske persepsjoner oppstår og forholdet til personlighetstrekk og kognitive mekanismer. Studien vil rekruttere friske studenter med høy og lav tendens til å hallusinere, og vurdere dem med en auditiv oppgave hvor de må oppdage stemmer skjult av støy. De vil også besvare ulike spørreskjemaer om personlighet. Studien består av to deler der man først vil rekruttere 600 deltakere til å gjennomføre et spørreskjema utarbeidet for å måle hallusineringstendens i utvalget. Deretter reduseres utvalget og deles inn i to grupper med 44 i hver gruppe, bestående av individer med enten høy eller lav tendens til å hallusinere.

REK vest ba om tilbakemelding på følgende:

- Revidert informasjonsskriv må sendes til REK vest.
- Revidert forskningsprotokoll må sendes til REK vest.

Tilbakemelding fra prosjektleder

- Forskergruppen har endret protokollen i henhold til krav i Forskrift om organisering av medisinsk og helsefaglig forskning § 8. Det er lagt til hypoteser og begrunnelse for hvorfor man ønsker å bruke de beskrevne spørreskjemaene.
- Informasjonsskrivet er revidert i henhold til komiteens merknader.

Vurdering av tilbakemeldingen

Prosjektleder har gitt en svært utfyllende tilbakemelding som besvarer komiteens spørsmål og merknader på en god måte.
I informasjonsskrivet bør begrepene "auditiv" og "språkprosessering" forklares. Setningen "All personlig informasjon vil bli behandlet anonymt" må erstattes med " All personlig informasjon vil bli behandlet konfidensielt".
REK vest har ellers ingen ytterligere merknader til studien.

Besøksadresse:
Armauer Hansens Hus (AHH), Tverrfløy Nord, 2 etasje. Rom 281. Haukelandsveien 28

Telefon: 55975000
E-post: post@helseforskning.etikkom.no
Web: http://helseforskning.etikkom.no/

All post og e-post som inngår i saksbehandlingen, bes adressert til REK vest og ikke til enkelte personer

Kindly address all mail and e-mails to the Regional Ethics Committee, REK vest, not to individual staff

Vedtak
REK vest godkjenner prosjektet i samsvar med forelagt søknad og tilbakemelding.

Sluttmelding og søknad om prosjektendring
Prosjektleder skal sende sluttmelding til REK vest på eget skjema senest 15.06.2020, jf. hfl. § 12. Prosjektleder skal sende søknad om prosjektendring til REK vest dersom det skal gjøres vesentlige endringer i forhold til de opplysninger som er gitt i søknaden, jf. hfl. § 11.

Klageadgang
Du kan klage på komiteens vedtak, jf. forvaltningsloven § 28 flg. Klagen sendes til REK vest. Klagefristen er tre uker fra du mottar dette brevet. Dersom vedtaket opprettholdes av REK vest, sendes klagen videre til Den nasjonale forskningsetiske komité for medisin og helsefag for endelig vurdering.

Med vennlig hilsen

Marit Grønning
dr.med. professor
komitéleder

Camilla Gjerstad
rådgiver

Kopi til: post@uib.no