A Cognitive examination of Top-down & Bottom-up Processes involved in the generation of False Auditory Perceptions: a Signal Detection analysis

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ABSTRACT

In a recent model, Waters and colleagues (2012) proposes that auditory verbal hallucinations (AVH) arise in hallucination prone groups due to an interaction between cognitive top-down and bottom-up process. This interaction has yet to be properly empirically tested. By employing the use of a signal detection task, this study examined the effects of noise (bottom-up) and semantic expectancy (top-down) on healthy participants screened for hallucination proneness (n=43). Participants were asked to listen to semantically manipulated sentences where the last word of the sentence was embedded or replaced by two different noise types, where one was based on human language frequencies while the other was the opposite. The hallucination prone sample showed a greater tendency to reporting hearing the word in the noise regardless of its presence when exposed to trials where the noise contained human language frequencies and high semantic expectancy sentences. This supports the theoretical model that AVH arise due to an interaction between top-down and bottom-up processes. Additionally, through a series of questionnaires, it was found that encoding style predicted performance on the task. Considering the specific significance between group, noise type and semantic expectation, tentative assumptions about encoding style's mediating effects on the interaction were made.

Keywords: Auditory verbal hallucinations, Signal detection task, White noise paradigm, semantic expectation, non-clinical sample

SAMMENDRAG

I en nylig modell av Waters og kollegaer (2012) ble det foreslått at hørselshallusinasjoner oppstår i hallusinasjonsutsatte grupper på grunn av en interaksjon mellom visse kognitive «top-down» og «bottom-up» prosesser. Denne interaksjonen har enda ikke blitt ordentlig empirisk undersøkt. Ved å ta i bruk en signaldeteksjonsoppgave så undersøkte dette studiet effekten av støy («bottom-up») og semantisk forventning («top-down») på en frisk gruppe av deltagere som var blitt forhåndsselektert basert på deres hallusinasjonstendenser (n=43). Deltagerne lyttet til semantisk manipulerte setninger, hvor det siste ordet av setningen var skjult eller fullstendig erstattet av en av to typer støy, hvor en var basert på menneskelige lydfrekvenser mens den andre var det motsatte. Gruppen med høy hallusinasjonstendens hadde en signifikant større tendens til å rapportere å høre ord i støyen uavhengig om den var der eller ikke da de var eksponert til lytteøvelser med støy komponert med menneskelige lydfrekvenser og setninger med høy semantisk forventing. Dette støtter den teoretiske modellen om at hørselshallusinasjoner dannes på grunn av en interaksjon mellom «top-down» og «bottom-up» prosesser. Ved hjelp av en serie spørreskjemaer ble det i tillegg oppdaget at innkodingsstil predikerte ytelsen på øvelsen. Tatt i betraktning den spesifikke signifikansen mellom gruppe, støytype og semantisk forventning, så ble tentative antagelser dannet om den medierende effekten av innkodingsstil.

Nøkkelord: Hørselshallusinasjoner, signaldeteksjonsoppgave, hvitlyd paradigmet, semantisk forventning, ikke-kliniske grupper

FOREWORD

The paper in front of you is the thesis "A Cognitive examination of Top-down & Bottom-up Processes involved in the generation of False Auditory Perceptions: a Signal Detection analysis" that researched the contributing mechanisms in the generation of false auditory perceptions in a non-clinical student sample by using methods and theories centred around the White Noise paradigm and Signal Detection theory. It was written as a part of my master's degree in behavioural neuroscience at the University of Bergen, 2018. The research and writing of this thesis took place between early Autumn of 2017 till late Spring 2018

The project was completed under the supervision of Julien Laloyaux, PhD. The project was challenging and advanced, but with the assistance and support from my supervisor and cooperation with my lab partner and fellow master student Karoline H.S. Sandanger we were able to successfully design, develop and run the experiment, and answer the hypotheses presented in this thesis.

I would like to thank Julien for his guidance and support on this project, especially the time he has invested in the supervision of this project, his level of availability and his readiness to assist with any questions or problems I might have concerning the study or the thesis itself. I also wish to thank my lab partner Karoline for an excellent partnership through the whole process, without whose cooperation and support I would not have managed to achieve the same satisfactory end-product. To Eujice S. Liwanan, I would like to thank you for your assistance with the construction of stimuli for the task as well. Finally, I would like to thank my friends and family for their endless support, you keep me motivated. A particular word of thanks to my parents, whose counsel and kind words have and always will be of great importance and help to me.

I hope you enjoy reading.

Elena Sørvig

Bergen, Norway, 24/05/2018

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Auditory hallucinations are in general considered a phenomenon that is exclusive to mental health issues and disease. Yet, its presence has shown to be indiscriminate of clinical and non-clinical status as it occurs regardless of the existence of any other symptoms or pathology associated with disease such as schizophrenia, personality or mood disorders, or neurodegenerative disorders (Blom, 2013). The ambiguity of its manifestation in clinical and non-clinical populations leave a lot to be desired in relation to understanding its' symptomatology and epidemiology, but especially its' aetiology. The study presented in this paper therefore examined some of the underlying cognitive mechanisms and processes contributing to the presence of auditory hallucinations in the healthy, general population. This was done by using theories from cognitive multidimensional models and the White noise paradigm to develop and gather results from an adapted version of an auditory listening task called the signal detection task.

1.1. Definitions, Prevalence & the Psychosis Continuum

One definition of auditory hallucinations is described by Waters and colleagues (2012) as, "auditory experiences that occur in the absence of a corresponding external stimulation and which resemble a veridical perception" (p. 683). Put simply, auditory hallucinations are the conviction of hearing or perceiving a sound or voice in the absence of actual auditory input from the outside world. Auditory hallucinations (AH), or more specifically auditory verbal hallucinations (AVH) where the perceived sound is heard in articulated words, is a common positive symptom in persons suffering from psychotic experiences. It is considered a frequent denominator in mental illnesses such as schizophrenia and is reported to affect approximately 70% of its diagnosed population (Tandon et al., 2013; \Waters et al., 2012; Wing, Cooper & Sartorius, 1974). It is also prevalent in populations diagnosed with bipolar disorder (15%), borderline personality disorder (20-50%) (Waters et al., 2012), and Parkinson's disease (9.7%) (Fénelon, Mahieux, Huon & Ziégler, 2000). Meanwhile, the evidence suggests that prevalence of AVHs in the general population ranges from 7% (Linscott & van Os, 2013; van Os, Linscott, Myin-Germeys, Delespaul & Krabbendam, 2009) up to an average of 15% as estimated from ten cross-sectional studies examining the general population of the western hemisphere (Blom, 2013).

There is some ongoing discussion about the presence of auditory hallucinations in healthy individuals and what implication this might have for how psychosis-related diagnoses should be regarded. This is grounded in the disparity of the psychosis phenotypes (i.e. the observable traits and attributes of an individual based the expression of their genetic code when it has been influenced by external environmental factors) between- and within the clinical and non-clinical populations, as positive symptoms such as AVH can greatly vary in their severity, intensity and frequency independent of diagnoses. An irregular expression of the psychosis phenotype has therefore led to an increasing number of studies and ideologies proposing the existence of a psychosis continuum with various degrees of normal and independent functioning rather than exclusive diagnoses and categories of psychiatric and neurological disorders (Bell, Halligan, & Ellis, 2006; Bentall, 1990; Daalman, Verkooijen, Derks, Aleman, & Sommer, 2012; Larøi, 2012; Larøi & Van der Linden, 2005; Moseley, Smailes, Ellison, & Fernyhough, 2015; Rossell, 2013; Vercammen & Aleman, 2010). A psychosis continuum is more versatile and adaptable to include and treat a broader range of individuals that does not necessarily fit within specific diagnostic criteria of psychiatric disorders, while also possibly bypassing some of the stigma surrounding mental health disorder. Additionally, the presence of a psychosis continuum could provide strong arguments for employing the use of hallucination prone, non-clinical samples in the investigation of psychosis and positive symptoms such as AVHs without the confounding variables often observed in clinical groups such as neurodegeneration, hospitalisation and medication (Vercammen & Alemann, 2010). Doing this does however present a challenge, as it remains uncertain whether the neural and cognitive abnormalities causing the arising of auditory hallucinations are shared across populations or whether there a distinct mechanisms and traits that are the cause of AVHs in clinical groups compared to non-clinical groups. To fully abide by the existence of a psychosis continuum these are challenges that need to be examined closer. It would nonetheless seem reasonable to presume that there are some shared underpinning cognitive or neurological mechanism that cause the generation of hallucinations in all populations.

Variations of the psychosis phenotype has had a significant impact on specific trait expressions that has caused a different level of functioning in the clinical from the healthy group, such as characteristics of the phenomenology and emotional regulation of AVHs (Catalan et al., 2014). For instance, AVH phenomenology in clinical populations are described as subjective experiences usually characterized by dominant, malevolent and omnipotent content considered intrusive and distressing, even though these traits do vary greatly on an individual level (Daalman & Diederen, 2013). In the non-clinical population these negative characteristics are far less frequent, as disclosed by Daalmann and colleagues (2011) who found that non-clinical persons experienced more positive and neutral phenomenology in their hallucinations compared to the clinical persons. This does not mean that clinical groups are exclusively experiencing hallucinations as negative, while non-clinical groups experience them as positive, as these traits are found to be interchangeable across populations (Larøi & Van der Linden, 2005). This suggests that phenomenology is not a crucial distinguishing factor between these groups, but rather the feeling of control and appraisal of the emotional content of the AVH as hallucinations are found to be cognitively mediated by beliefs about voice identity (Garety, Kuipers, Fowler, Freeman & Bebbington, 2001). Furthermore, this indicates that although AVHs could be caused by common neural and cognitive mechanisms in both populations, there are some critical differences in appraisal of symptoms that causes the impedimental acceptance that these two groups should be regarded as separate. This might have acted as a potential deterrent in using non-clinical samples void of confounding variables to investigate the auditory verbal hallucinations as a phenomenon in earlier studies.

1.2. Theories of Auditory Hallucinations & Models of Cognitive Mechanisms

Because of this possibility of an existing psyhosis continuum, it is important to acknowledge the complexity of AVH generation when appraising the source of hallucinatory experiences, and that it might require cross-disciplinary explanations as no single level of explanation (i.e. cultural, clinical, cognitive, brain imaging, cellular, and molecular levels) is sufficient to explain its onset as pointed out by Hugdahl and Summer (2017). Even on just a purely cognitive level, auditory hallucinations have been related to a number of mechanisms and traits. A common assumption is that AVHs can be ascribed to abnormal self-monitoring of internally generated thoughts and events that is attributed to the external environment (Bentall, 1990; Dollfus, Alary, & Razafinmandimby, 2013; Larøi, 2012; Larøi et al., 2012; Vercammen, de Haan & Aleman, 2008; Waters et al., 2012). This theory is based on the supposition that voice-hearers mistake private thoughts or imaginary internal events for extrinsic stimulus and attempt to compensate for this type of misattribution in terms of a variety of cognitive defects such as abnormalities of peculiarly vivid mental imagery (Bentall & Slade, 1985; Mintz & Alpert, 1972). Waters and colleagues (2012) do however argue that the evidence for this type of self-monitoring is not specific for hallucinations but rather applicable to all positive symptoms in schizophrenia. They state that AVHs should rather be regarded as perceptions that emerge through “an interaction between information arising from neural activations and top-down activity” (pp. 688). From this, they designed a cohesive multidimensional cognitive model that at large regards auditory hallucinations as perceptions that are generated through an interaction between neural activations and functional brain systems. One of the main arguments in their model is that AVHs may in part present a deficit in signal detection that causes increased detection of ambiguous or salient signals and an increased likelihood of accepting those signals as present and real. This claim is based on the assumption that hallucinations arise from perceived aberrant signals that cause hyperactivation of the auditory cortex, as well as a combination of different top-down mechanisms that constitute various modes of cognitive control and error-processing that creates a personalised, and in this case, erroneous perception of reality. Hallucinations are in this view mediated by deficits in intentional inhibition that causes a lack of insight about the set of beliefs linked to the AVHs as well as a reduced sense of control over perceptual experiences. These experiences are influenced by memories and expectations that make the hallucinations personally relevant, while emotional regulation impacts all aspects of this perceptual processing. All of these constitute a combination of various bottom-up and top-down processes that contribute to the generation of hallucinations due to how these mechanisms appraise an external auditory signal. An interaction between such cognitive processes and a failure to suppress the wrongly perceived information (i.e. auditory signal) due to intentional inhibition deficits would contribute to the failure of successfully containing and controlling the signals. This is the cause of what they refer to as a 'First hit' of a traumatic insult, which is modulated by attributes such as emotional state and appraisal. After the first traumatic insult, the likelihood of these experiences being repeated depends on level of expectations, insight, potential delusional beliefs and hypervigilance, which would over time cause a readier acceptance of the auditory signal as being real as a result. Waters and colleagues (2012) particularly emphasise the prominent role of emotion at all cognitive levels of their model, suggesting that emotion could be the provider of hallucinations' ontogenesis (the 'first hit') as well as contributing to and modulating all other influential mechanisms involved in hallucination generation, as well as its' key characteristics and content. For instance, phenomenological variations of auditory content are explained primarily by individual differences in severity of deficits and localisation of neural activity, which is directly affected by emotional processing that may create a vulnerability for psychotic experiences. Such a cognitive model appears reasonable as neuroimaging studies have directly linked occurrences of AVHs with brain regions involved in speech generation, speech perception and verbal memory (Barkus, Stirling, Hopkins, Mckie & Lewis, 2007; Copolov et al., 2003; Dierks et al., 1999; Lennox, Park, Medley, Morris & Jones. 1999; Shergill, Brammer, Williams, Murray & McGuire, 2000; Silbersweig et al., 1995). The differences in neural structures and activity of the ventral 'what' and dorsal 'where' pathways in the Dual-

Stream network proposed by Hickok and Poeppel (2007) could potentially determine abnormal cognitive mechanisms and functioning, particularly in the verbal versus non-verbal quality of the hallucination and intrinsic-extrinsic distinction (Waters et al., 2012).

An important theory Waters and colleagues (2012) based their model upon is Bentall and Slade's (1985) Signal detection theory (SDT). This states that all information processing takes place under some uncertainty, and that processing relies on perceptual sensitivity (i.e. the level of which one is able to distinguish signals from irrelevant noise) through pattern recognition and response bias (Bentall, 1990; Bentall & Slade, 1985; Hoskin, Hunter & Woodruff, 2014). Response bias (β) is a measure that depend on fixed internal schemata that affect participants' criterion for determining a response in regard to a stimulus, such as memories or feelings associated with or evoked by the stimuli, the quality and loudness of the stimuli, as well as other variables (Stanislaw & Todorov, 1999). The SDT also proposes that mistakenly perceived external attributions are preceded by processing errors in the reality discrimination pathways (Bristow, Tabraham, Smedley, Ward & Peters, 2014). SDT is grounded in two subjacent theories, one of them being the assumption that hallucinating individuals are poor at reality testing, a metacognitive skill that can, under certain conditions, make the individual mistake imaginary events as real and vice versa (Johnson & Raye, 1981). Bentall and Slade (1985) argued that reality testing is most likely a component that is reflected in and affect other perceptual errors observed in clinical groups with hallucinatory experiences, such as their poorer performance in locating spatial source of sound compared to control (Heilbrun, Blum & Haas, 1983). The second theory is the source monitoring hypothesis, that suggests hallucinating individuals have more lenient decision criteria for accepting signals from either an external or internal source as real which cause a higher frequency of misattribution of salience (Bentall & Slade, 1985). These types of phenomena can most likely be related to hallucinating individuals being relatively unfamiliar with their own mental processes and thoughts (Heilbrun, 1980), and could attribute to these groups showing bias in their confidence in perceptual judgement tasks which is reflected their performance, response-time and accuracy on cognitively demanding tests and measures (Burgess, Simons, Dumontheil & Gilbert, 2005). Collectively, these errors contribute to an inability to distinguish meaningful signals (e.g. someone calling your name in a crowd) from insignificant noise (e.g. chatter in a crowd), thereby wrongly perceiving signals that are non-existent (e.g. hearing one's name being called in an unfamiliar crowd) and cause the arising of unusual perceptions. This type of wrongly perceiving stimuli is called 'false alarms'. In relation to auditory hallucinations, these types of false alarms might arise through a lowered sensitivity, accompanied by a more liberal response bias (Hoskin et al., 2014). A decreased sensitivity would cause more perceptual errors to be made overall due to an increased difficulty in identifying signals as they sound more muted because of their perceived lesser value, making it harder to discern it from meaningless noise (Stanislaw & Todorov, 1999). Meanwhile, a liberal criterion is a response bias where participants have a tendency toward reporting a signal in the noise regardless of its presence and indicates a higher rate of false alarms. Response bias (β) and depends on the standardised rate of false alarms ($Z(FA)^2$) and standardised hits per participant ($Z(H)^2$), and is calculated by using the formula [$\beta = \sum \{\frac{Z(FA)^2 - Z(H)^2}{2}\}$] (Stanislaw & Todorov, 1999). Here, a response bias value below one indicates a liberal criterion while a value above one indicates a conservative criterion, which is the opposite of a liberal criterion.

1.3. The Development of the White Noise Paradigm & Signal Detection Task

Such types of perceptual errors as false alarms, sensitivity and response bias are measurable, and one of the first instances of this can be observed in the classic study by Barber and Calverley (1964) where healthy participants were told to listen to the record '*White Christmas*' without the stimulus actually being present. In this study they examined the effects of AVH generation through the use of hypnosis treatments and suggestion by telling participants Bill Cosby’s song was being played through a phonograph when it actually was not. Overall, a total of 54% of their participants reported hearing the suggested music, with hypnotised persons being more open and responsive to suggestion of music presence than controls. Barber and Calverley (1964) proposed this was due to peculiarly vivid mental imagery, but later studies argued that these results might reflect a liberal bias towards believing the stimuli was actually present (Bentall & Slade, 1985). Such experiments paved the way for the White Noise paradigm and the signal detection task by Bentall and Slade (1985) that has been implemented on a grander scale when it comes to testing measures such as false alarms and similar cognitive mechanisms. In particular, it has been used to test the presence of AVHs in clinical and non-clinical populations versus controls using white noise, i.e. a complex, discreet noise that is composed of frequencies across the sound spectrum.

The original study by Bentall and Slade (1985) was a signal detection task where non-clinical participants (experiment 1) and clinical participants with schizophrenia (experiment 2) were told that they were going to get their hearing tested. Participants were asked to listen to bursts of white noise and report whether they had been able to detect a signal (i.e. a word) in the noise. Both clinical and non-clinical participants were screened based on their LSHS scores, which is a scale designed to measure hallucination proneness (Launay & Slade, 1981), and were compared to control groups. The task consisted of two stimuli, a pure white noise condition, and a white noise condition where a signal was hidden in the noise. These were equally divided between 100 randomly ordered listening trials. The signal embedded in white noise was the word “who” which was played 3 seconds after the onset of white noise if it was the condition where the signal was present. In that condition, the signal-to-noise ratio was barely audible or perceivable. Their results indicated a significant group difference in the task, where participants with higher scores in the LSHS displayed a much more liberal criterion compared to controls. This was also the reflected in the results for the clinical groups, where hallucination prone patients displayed a much more liberal response bias compared to healthy controls. There were however no significant group differences in sensitivity in the clinical nor the non-clinical groups. Bentall and Slade (1985) concluded based on their findings that this supported their hypothesis that hallucinators were poorer at reality testing and more readily accepted the signal as present. This was consistent with their proposed hypotheses of the SDT, which they claimed was also furthered strengthened by previous findings by Mintz and Alpert’s (1972). They conducted a study using the White Christmas test (Barber & Calverley, 1964) where they observed that clinical hallucinators were more willing to accept that the record had been played than controls. Mintz and Alpert’s (1972) study was similar to Barber and Calverley (1964) in methodology, except it examined schizophrenic patients with and without auditory hallucinations. From this, it was proposed that cognitive abnormalities underlying AVH generation could be caused by an inability to discriminate peculiarly vivid mental imagery from exteroceptive stimuli (Mintz & Alpert, 1972). Their assumptions on vivid mental imagery is similar to the hypothesis that AVHs arise from abnormal self-monitoring that Waters and colleagues (2012) argued was not necessarily specific to hallucinations.

This is a criticism that Waters and colleagues (2012) also directs towards the SDT as they consider it to be too unspecific and does not exclusively discriminate for AVHs’ state characteristics such as insight, belief systems, and perceptual and emotional quality. This is emphasized by findings presented by Harvey (1985) who argued that reality testing differs depending on diagnoses. For instance, persons diagnosed with mania struggles with external discrimination of auditory stimuli, whilst persons diagnosed with schizophrenia have problems with discriminating external from internal stimuli, which would imply that reality testing deficits is not specific to AVHs but rather other accompanying symptoms in different diagnoses. This discrepancy in the basic argument of SDT is demonstrated by Mintz and Alpert (1972) who argued that their findings was less likely due to poor reality testing but rather exceptionally vivid mental imagery despite Bentall and Slade's (1985) later claim of support. Waters and colleagues (2012) therefore concluded that reality testing is more reasonably linked to delusions due to its' nature of making rapid and overconfident judgements, and that the assumption that reality testing was part of AVHs and SDT originally was due to the shared cognitive processes that is common in many positive symptoms in various diagnoses.

1.4. Replications & Variations of the Signal Detection Task

To date, the signal detection task has been replicated on numerous occasions, and the SDT does seem to be strongly supported in the assumption that persons exhibiting AVH symptoms are more likely to report false alarms (Bentall & Slade, 1985; Hoskin et al., 2014; Mintz & Alpert, 1972). Yet, there are contradictory conclusions as to what the exact cause of a higher rate of false alarms across both clinical and non-clinical populations is. For instance, a liberal response bias has been observed in both clinical (Vercammen, de Haan & Aleman, 2008) and non-clinical samples (Vercammen & Aleman, 2010), where hallucination prone individuals significantly differed from healthy controls by being more affirmative during trials by reporting more false alarms. In a study by Vercammen and Aleman (2010), they measured performance of healthy participants screened for hallucination proneness by using a modified signal detection task that also measured the effects of semantic expectation on the rate of false alarms. They employed a somewhat similar methodology to Bentall and Slade (1985) where they asked participants to listen for and identify words embedded in or replaced by white noise. As an additional variable, they constructed 150 sentences consisting of 5 – 7 words. These were produced to accompany the bursts of white noise that masked the final word of each sentence which was manipulated to be of either high or low sematic expectancy. The sentences were equally split into categories of high and low semantic expectation (75/75), where one-hundred of the sentence trials' end-words was embedded in white noise, whilst the remaining fifty sentence trials' end-words were entirely omitted from the sentence and replaced by the white noise. All the trials were randomized in their order. With the additional variable of semantic expectation, Vercammen and Aleman (2010) discovered a positive correlation where the number of top-down errors increased along with the increase of LSHS scores in participants. There was also a significant difference in perceptual sensitivity where high proneness individuals had more hits and correct rejections compared to controls. This difference was prominent in the condition where the stimuli was within a high semantic expectancy context as participants with high hallucination proneness were more likely to report hearing and identify the target word even while it was not present. In a similar speech discrimination task on a clinical sample diagnosed with schizophrenia with AVH symptoms, Vercammen and colleagues (2008) found analogous results of enhanced sensitivity to speech stimuli and a more positive response bias in hallucination prone individuals. Based on the assumption that clinical and non-clinical hallucination prone samples are actually not mutually exclusive but rather exist on a psychosis continuum, it is possible to draw tentative inferences that the results observed in the signal detection task is due to a combination of semantic expectation, sensitivity and a more liberal criterion amongst hallucination prone individuals, rather than deficits in e.g. reality testing or self-monitoring as previously proposed by earlier studies.

Waters and colleagues' (2012) model do however strongly argue for a multidimensional view that takes into consideration the complex interaction between top-down and bottom-up processes in order to fully understand such erroneous perceptions as AVHs. They particularly emphasise how top-down and bottom-up processes regulate factors such as emotion, expectations and beliefs in hallucination onset and modulation. The exact cognitive mechanisms that contribute to the governing of these factors remains unclear however, but it can be assumed that abnormalities in these mechanisms can influence perceptual processes and act as predictors in performance during signal detection tasks.

An example of such a predictor can be found in a study by Hoskin, Hunter and Woodruff (2014) where they investigated the mediating effects of trait anxiety and stress on performance during a signal detection task. In their adaption, they implemented a 2x2x2 fully factorial research design that manipulated semantic expectation, level of stress and hallucination proneness in groups. They presented non-clinical hallucination prone participants and controls with 48 signal detection trials where they had to listen to sentences spoken by a neutral voice where the last word was either embedded in or replaced entirely by 1000 milliseconds of white noise. They were asked to report whether they heard any speech in the noise or not. In a similar vein to Vercammen and Aleman (2010), Hoskin and colleagues (2014) manipulated the semantic expectation of the sentences in such a way that some generated a level of high expectancy while some did not. However, instead of just manipulating the expectancy of the end-word signal, they constructed and manipulated the expectancy of entire sentences in such a way that one would prime participants for the end-word, while the other would make it difficult to correctly guess what the end-word could be.

A third variable was also introduced where participants' psychological stress was manipulated by being shown images with or without adverse content. As with the results found by Vercammen & Aleman (2010), this study found a significant effect of semantic expectation on response bias, which had a positive impact on participants' sensitivity and an observed effect of a more liberal criterion in the hallucination prone group. Additionally, Hoskin and colleagues (2014) found that trait anxiety predicted performance on the signal detection task, and that psychological stress had an impact on response bias. This resulted in persons reporting higher levels of stress having more false alarms due to a more liberal criterion and increasing the likelihood of erroneous perceptions of the speech stimuli. Contrary to previous findings however, Hoskin, Hunter and Woodruff (2014) did not find any relation between response bias and LSHS scores or schizotypy in their population.

Merckelbach and van de Ven (2001) argued that it was possible that mechanisms such as trait anxiety could be better predictors of performance than hallucination proneness itself. In their study, they examined the relationship between hallucination proneness and fantasy proneness by using parts of Barber and Calverley (1965) White Christmas test and implementing the use of white noise from the original signal detection task (Bentall & Slade, 1985) which was not included in the original White Christmas test. Here, healthy participants (n = 44) were asked to listen to white noise for a 3-minute period and told the Bill Cosby song might or might not be embedded in the noise. Participants were asked prior to the beginning of the experiment whether they were familiar with the song, which the experimenters were playing in the testing room upon participants' entry. After the 3-minute period, participants were then instructed to report whether they heard the White Christmas song in the noise, even though it had in fact never been present in the white noise at all. They also completed a series of questionnaires that controlled for several cognitive mechanisms such as social desirability and mental imagery, in addition to the LSHS and the Creative Experiences Questionnaire (CEQ; Merckelbach, Horselenberg & Muris, 2001) that measured fantasy proneness. The definition for fantasy proneness is that it is a profound and heavy involvement of imagination and imaginary events (Lynn & Rhue, 1988), which cause an increased susceptibility to producing pseudo-memories (Hyman & Billings, 1998). Merckelbach and van de Ven (2001) found that 32% of their participants reported hearing the White Christmas song in the white noise, and that these participants scored significantly higher on both the LSHS and the CEQ. However, based on the results from the regression analyses they proposed that fantasy proneness might be a better predictor for the performance on the task than hallucination proneness. There were discovered similar results in a previous study by the same first author that also examined this trait, where they found that higher fantasy proneness was a better predictor for hallucinatory experiences since this is a trait that tends to endorse odd items that might be perceived during the recording of white noise (Merckelbach, Muris, Horselenberg & Stougie, 2000). It is however argued that there is a possibility that fantasy proneness might be a trait that merges into the broader category of schizotypy, and that fantasy proneness as an independent mechanism might not sufficiently explain why some individuals experience AVHs and not others (Merckelbach & van de Ven, 2001).

This argument raises an interesting point and could explain some of the irregularity in results across multiple studies where there is a discrepancy in reports of false alarms, response bias and sensitivity, and how these relate to hallucination proneness in both clinical and non-clinical samples. An example of this discrepancy is Bentall and Slade (1985) and Hoskin and colleagues (2014) who found different results for whether hallucination proneness predicted response bias. It is possible that this is grounded in inconsistencies in screening criteria, and that some studies use too broad or unspecific screening criteria in their studies. For instance, studies employing the use of the entire LSHS will also include items unrelated to AVHs as the LSHS covers a broader spectrum of hallucinations and abnormal experiences by including questions assessing e.g. visual hallucinations and daydreaming, amongst others (Launay & Slade, 1981). In the case of the White Noise paradigm, it should be a prerequisite to use focused items that measure only a single factor (i.e. auditory hallucinations). This is to mainly avoid the founding variables of schizotypy and other hallucinations, and to have proper control and insight into what is actually being measured as a high overall schizotypy score could refer to a wide variety of symptoms. Also, because schizotypy is very encompassing and nonspecific, it can cause contradicting conclusions across studies as the samples might vary depending on confounding external factors such as cultural and social aspects. This might be the case of Merckelbach and van de Ven (2001) and why they found no significant association between hallucination proneness and performance during the White Christmas task, as they employed the use of the whole LSHS rather its specific AVH items. A study by Pries and colleagues (2017) where their aim was to investigate the relationship between speech illusions in a signal detection task and expression of psychotic symptoms in non-clinical populations bears similar vacillations to Merckelbach and van de Ven's (2001) study. Pries and colleagues (2017) employed the use of the Structured Interview for Schizotypy – Revised (SIS-R) and the Community Assessment of Psychic Experiences (CAPE) to assess their sample, both of which measure schizotypy and psychosis proneness rather than auditory hallucination proneness. They concluded that erroneous perceptions and speech illusion during such a task was not associated with psychosis proneness in non-clinical populations contrary to findings in clinical samples. It could be that the results found in clinical samples from previous studies are not reflected in their non-clinical sample due to the lack of specificity of such scales and that non-clinical samples tend not to have the same level of comorbidity as e.g. a schizophrenic sample, which is why high scorers in SIS-R and CAPE in clinical samples might have high rates of false alarms when non-clinical groups do not. Schizotypy therefore leaves a lot to be desired in relation to how to interpret the data from tasks adapted from the White Noise paradigm.

1.5. Potential Cognitive Predictors of False Perceptions

It is therefore important to be mindful of these distinction between hallucination proneness and schizotypy as it might influence results. Mechanisms that have shown to be associated with schizotypy should nonetheless be examined closer as potential predictors on performance during signal detection tasks. Hoskin and colleagues (2014) examined trait anxiety as a predictor for performance, and Merckelbach and van de Ven (2001) presented fantasy proneness as a potential predictor for false alarm rates in non-clinical populations, but Waters and colleagues (2012) also promoted the link between hearing voices and dissociation. Dissociation is “a disruption of and/or discontinuity in the normal, subjective integration of one or more aspects of psychological functioning” (Spiegel et al., 2011, p. 826), or put differently, dissociation is mental detachment or loss of reality by disconnecting from physical and emotional experiences. It has been found to be significantly associated with both hallucination proneness (Alganami, Varese, Wagstraff & Bentall, 2017) and schizotypy (Barkus et al., 2007) which suggests its involvement in a broad range of positive symptoms. This also makes it seem logical to assume that it could potentially be linked to the generation of AVHs. Further, Alganami and colleagues (2017) proposed that dissociation might have an impact on source monitoring as it causes a deficiency in attending to the immediate surroundings and happenings which affects contextual and psychological factors that determines whether and when auditory hallucinations occur (Bentall, 1990), and might increase the likelihood of firing of neural activation associated with aberrant auditory signals (Waters et al., 2012).

Another possibility is that hallucinations arise from the brain attempting to assign altered importance or emotional value to irrelevant or meaningless stimuli which affects cognitive schemata and an individual’s ability to appropriately processes their immediate surroundings (Kapur, 2003). This sort of cognitive process is known as aberrant salience and has been shown in past studies employing the use of the signal detection task to correlate with speech illusions and schizotypy in clinical samples (Catalan et al., 2014; Catalan et al., 2018; Galdos et al., 2011) and also positive symptomatology in other studies implementing different methodologies (Roiser, Howes, Chaddock, Joyce & McGuire, 2013). However, whether aberrant salience reflect psychosis expression in healthy participants in white noise tasks remains uncertain (Gonzalez de Artazal, Catalan, Angosto, Valverde, Bilbao, van Os & Gonzalez-Torres, 2018). An aberrant salience hypothesis was proposed by Kapur (2003) that suggests that positive symptoms (i.e. delusions and hallucinations) reflects impaired mechanisms that wrongly assigns salience or importance to ambiguous stimuli due to dysregulated, hyperdopaminergic levels in the brain that mediates external events and internal representations. In this view, hallucinations reflect “a direct experience of the aberrant salience of internal representations” (Kapur, 2013, p. 13). In turn, this can cause disturbed perceptions of auditory stimuli in the external environment. It would not be unreasonable to assume this effect is particularly prevalent during signal detection tasks for individuals who displays aberrant salience as they are more likely to attribute patterns to meaningless signals such as white noise.

If hallucinations reflect amplified and exaggerated internal precepts (Bentall, 1990; Kapur, 2003) it would also be possible to assume that individual encoding style might have a substantial impact on signal detection. Encoding style is the tendency to self-perpetuate interpretive representations and schemata onto stimulus. This is done by filtering and limiting attention and awareness of what is noticed about the stimulus in question and determining the following order of actions to be taken based of implicitly acquired knowledge about the stimulus (Lewicki, 2005). Encoding style can be considered as two-dimensional depending on the speed of which the immediate surroundings are perceived. A slow processing speed indicates a conservative, external encoding style that is attached to the external evidence, whilst a fast processing speed indicates an internal style that relies excessively on expectations shaped by past experiences (Lewicki, 2005). An internal encoding style has in previous investigations been found to be strongly related to positive schizotypal traits and abnormal perceptual experiences (Belayachi, Laloyaux, Larøi & Van der Linden, 2014). Moreover, it would appear that the more internalized the encoding style, the greater is the likelihood that external cues could be interpreted by pre-existing, internal interpretive representations and increases the risk of “split-second illusions”, which is the tendency to incorrectly perceive and recognise something specific e.g. object or animal, only to realize moments after that it was something else (Belayachi et al., 2014). “Split-second illusions” might increase the risk of erroneous perceptions and possibly contribute to the generation of false alarms by imposing imperfect or wrongly perceived encoding schemata onto stimuli (Lewicki, 2005).

Mechanisms and traits such as fantasy proneness (Merckelbach & van de Ven, 2001), dissociation (Waters et al., 2012), aberrant salience (Kapur, 2013) and encoding style (Lewicki, 2005) could act as predictors for performance on signal detection tasks. Additionally, they account for some of the top-down processes proposed to potentially contribute to the generation of AVHs in the model by Waters and colleagues (2012), although these are not adequate in trying to explain the bottom-up processes involved. In the case of the White Noise paradigm and SDT, the bottom-up processes would be dependent on the type of noise used during these auditory tasks, and the aberrant signals that emerge from those noise types. There is a quite a few studies that have implemented the principles and methodologies of Bentall and Slade (1985) which were amongst the first to introduce this type of tasks by using white noise, yet the exact reason why white noise was selected as a stimulus and why this specific type of noise causes an increase in false alarms in selected samples remains unclear. It is possible to assume that hyperactivity in the auditory areas arise from specific frequencies composing the white noise and not others, and also that the human hearing is not equally sensitive to all the sound frequencies comprising white noise. It is also possible that that this is the case with the words presented as well, as participants would be more sensitive to certain words, sometimes independent of semantic expectancy, but rather recognition of specific pitches and drops to those words. It could also be a confounding effect of the voice that is used to say the words as voice pitch and depth is often related to sex of the speaker, and this might have an impact on how easily it is to discern it from white noise. Finally, the type of headphones used during tasks might influence perception as poor headphones could potentially generate human language frequencies on their own due to their reduced quality and thereby contribute to the generation of false alarms, despite there being no purposeful or intended external stimuli causing this perceptual error in underlying bottom-up processes. To investigate the quality and characteristics of white noise could therefore potentially reveal the involvement of bottom-up processes in the generation of false alarms and AVHs, and in addition uncover whether auditory hallucinations are specific to certain types of noise as opposed to others.

1.6. Aims & Hypotheses

The aim of the present study was to further investigate the SDT and the effects of random noise on healthy, hallucination prone participants by examining cognitive top-down and bottom-up processes and mechanisms. Variables such as level of semantic expectancy were examined in their involvement of elicitation of false alarms and hallucinatory-like experiences. These variables were integrated into a new signal detection task that implements a similar methodology to Hoskin and colleagues (2014). In addition, this study added another variable that controlled for bottom-up processes by manipulating the sound frequencies composing the white noise by creating two new noise types, where one contained human language frequencies (the human noise) while the other did not (the non-human noise). These replaced the white noise stimulus in the signal detection task. This test was designed to test whether specific sound frequencies contribute to activation in the brain that cause hallucination-like experiences, and whether there was an interaction between top-down (semantic expectancy) and bottom-processes (noise type) that causes the onset of hallucinations as suggested in the model by Waters and colleagues (2012).
Put differently, the study employs a 2x2x2 fully factorial design that compares the performance of high hallucination prone individuals with low hallucination prone individuals in detecting signals in noise by varying the semantic expectancy of the sentences in the task, as well as the type of noise that the end-words will be replaced or embedded in. A last aim of the study was to examine the effects of predictors on response bias and false alarms in the task. This was done by exploring the impact of other cognitive processes such as fantasy proneness, aberrant salience, dissociation and encoding style, and see how these traits affected task performance. Based on the existing literature, the following hypotheses were drawn: In accordance to previously observed findings, an overall significant group difference in response bias and false alarm are expected, with an increased rate of false alarms and a more liberal response bias in the high hallucination proneness group compared to the group with low hallucination proneness (hypothesis 1). Moreover, in accordance with Hoskin and colleagues' (2014), hallucination prone individuals are expected to have lower sensitivity compared to the low proneness group (hypothesis 2). A difference in response bias, false alarms and sensitivity is also expected in the human noise compared to the non-human noise, with an observed increase of rate of alarms, a lowered sensitivity and a more liberal criterion in the human noise as this is the noise with the human language frequencies derived from the white noise (hypothesis 3). From the results in Hoskin et al. (2014), and Vercammen and

Aleman (2010), semantic expectation is assumed to affect performance by the signal detection task, with high semantic expectation causing an increase in rate of false alarms but also increase sensitivity (hypothesis 4). Based on the claims in Waters' et al. (2012) model a significant triple-interaction effect between group, noise type and semantic expectation is expected, with possible individual interactions dependent on the combinations of noise type and semantic expectation between groups (hypothesis 5). Even though it is expected to be observed an effect on response bias and false alarms based on the grouping variable of hallucination proneness, other cognitive mechanisms might act as predictors that influence these measures further. High scores on self-reports of dissociation, encoding style, fantasy proneness and aberrant salience will therefore be explored to see if they predict performance on the signal detection task between groups (hypothesis 6).

METHODOLOGY

The study was approved by the Regional Committee for Medical and Health Research Ethics (REK) on the 14th of February 2018, reference number 2017/2490/REK vest (see Appendix A).

2.1. Participants

2.1.1. Screening Phase

This sample was collected from the general population, and the participants had to be between eighteen and thirty years old. By following these inclusion criteria, a total of 285 participants were recruited to be screened for low- and high hallucination proneness. Out of these 189 were female (mean age = 21.49, SD = 3.45), while 89 were male (mean age = 22.80, SD = 4.72), and 12 remained refrained from reporting their sex. Participants were recruited through the University of Bergen, mainly by utilizing lectures and classes where a large sample of students were present. The students had mixed backgrounds in terms of their field of study, including Geography, Medicine, History, English, Psychology etc. An exclusion criterion for this study was that participants could not have any neurological or psychiatric diagnoses, or hearing loss. Out of the 285 participants, 6 reported hearing loss, 29 reported current or previous psychiatric diagnoses and 4 reported current or previous neurological diagnoses. These thereby had to be excluded from the second part of the study. The remaining 246 participants were considered further based on their scores in the revised Launay-Slade Hallucination Scale (Launay & Slade, 1981; Larøi & Van der Linden, 2005).

2.1.2. Experimental Phase

Following the screening phase, a sample of 43 participants were selected based on their scores on the AVH items in the LSHS. Out of these, 13 females and 10 males (mean age = 20.87, SD = 2.03) scored high on auditory hallucination proneness. This dictates that they recorded a minimum of score of 3 or 4 in two or more AVH items. Meanwhile, 14 females and 6 males (mean age = 22.50, SD = 2.39) were selected for the low proneness group based on item scores of less than 1 in maximum two AVH items, which was compared cross-sectionally to their total LSHS scores between 0 and 10. There was no difference between gender distribution between groups (x^2 (1) = 3.832, *p*.>0.05), although a significant difference was observed in participants' age across groups (*t* (41) = 2.417, *p*.<0.05). Repeated measure

ANOVAs showed however no significant effects of age on the total response bias, sensitivity or false alarm rates. All participants were contacted by phone a couple of months following the screening phase to schedule an appointment to conduct the study, which took place in one of the audio labs at Haukeland University Hospital.

2.2. The Signal Detection Tasks

The study is adapted largely from Hoskin et al. (2014). Deriving techniques and procedures from their methodology, this study asked screened participants the complete an auditory trial where they had to listen to 140 recorded sentences with the last word either embedded or entirely replaced by one of two noises. These two noises are the human noise, that is derived from human language frequencies in white noise, and the non-human noise that is manipulated to sound as the exact opposite to the human noise. Further, sentences were constructed to generate either a high or low semantic expectancy. Participants were asked to report whether they had been able to detect the end-word (signal) in these noises or not. The sentences were sudo-randomised by their semantic expectancy, type of noise, and presence/absence of the signal in each sentence. Depending on these factors and the participants' responses, data such as false alarms, hits, misses and correct rejections were collected, and was used to determine participants' sensitivity, response bias and misperception of signals.

2.2.1. Sentences

A pilot study was conducted to create the semantic sentences. Here, a total of 160 sentences were formulated for the purpose of controlling for high and low semantic expectancy, with all of them being made in Norwegian to suit the sampled population. The sentences were designed to be emotionally neutral and impersonalised by avoiding usage of words such as "I", "you", "us" and "we", as well as avoiding the use of names. Out of the constructed sentences, 80 were manipulated with the intention to prime participants so they had a high level of expectancy of what the ending word could be (e.g. The apple fell from the **TREE**), while the remaining 80 were created to cause a low semantic expectancy (e.g. The best would be to **MARRY**). 12 participants were given these sentences in an excel sheet where the last word of the sentence was removed, and they were asked to complete the sentence with the word they deemed the most appropriate. The results were considered by the internal consistency, or lack thereof, between the participants' answers. The pilot study for these sentences had to be conducted twice to ensure sentence validity, since the first review of the internal consistency did not sufficiently meet the requirements and parameters set in advance of testing. Primarily, these parameters were that the sentences in the high sematic expectation category had to have a universal agreement above 80%, whilst the sentences with low expectancy were below the 35% set cut-off. The sentences that did not meet these requirements were either reconstructed or replaced entirely, and the pilot was conducted for a second time with 20 naïve participants that did not take part in the initial testing. The second pilot study tested a total of 164 sentences. The same validation measures used in the first pilot were used to consider the sentences here. This resulted in 70 semantically expectant sentences being above the 80% specification, while 70 of the non-expectancy sentences were below the 35% agreement limit. A total of 140 sentences were thereby divided by their sematic expectancy, and either embedded or entirely replaced by noise as seen in the paradigm by Hoskin, Hunter and Woodruff (2014), which resulted in four distinct categories:

1. Semantic expectation word + noise: e.g. The florist sold them **FLOWERS**
2. Semantic expectation only noise: e.g. The florist sold them ****
3. No semantic expectation word + noise: e.g. The florist visited their **SISTER**
4. No semantic expectation only noise: e.g. The florist visited their ****

All 140 sentences and end-words were read by a male voice and a female voice, which was recorded in the audio lab at Haukeland University Hospital. Both the male and female voice had a Bergen dialect that were emotionally neutral, easily understandable and had no distinct characteristics or speech-impediments.

2.2.2. Human & Non-Human Noises

There were two noises designed for the purpose of this study the human noise and the non-human noise, both of which were manipulated to vary significantly in their sound-properties to measure the effect of distinct characteristics in white noise and the impact of bottom-up processes on the perception of sound in auditory hallucinations. The human noise was constructed based language frequencies called formants presented by Hillenbrand, Getty, Clark and Wheeler (1995), who investigated a population consisting of both males and females, and their acoustic voice characteristics of vowels within the formant range $F_0 – F_4$. A formant is a concentration of energy appearing as spectral prominence around a particular frequency on the speech spectrum (Fant, 1960 cited in Titze et al., 2015; Wood, 2011), where the F refers to the specific formant frequency across the speech waveband (Titze et al., 2015). In human speech, F_0 is the fundamental frequency that determines gendered properties of a voice, while tones and pitch can be characterised by F_1 and F_2, and formants in the higher F frequencies are more associated with singing voices (Wood, 2011). The values that were presented in the journal by Hillenbrand and colleagues (1995) were averaged across formants F_0, F_1, F_2 for male and female voices. In addition, these values were also averaged between each formant level (i.e. average value of F_0 and F_1, F_1 and F_2), to then be combined and used to generate the human noise. The higher and lower cut-off values in this sound were derived from white noise. The distinct spectral peaks were smoothed out into even slopes for formant frequencies F_0, F_1 and F_2, and slopes down steeply to remove higher F3 frequencies, both of which removed unwanted noise in the recording. Meanwhile, the non-human noise's sound-frequency is reversed to sound the least amount as human speech as possible (so potential hits can be related back to the whether it is formants triggering false alarms) with the opposite characteristic of the human noise. The non-human noise is still based upon the white noise except in this condition the majority of frequencies were removed for F_0, F_1 and F_2. The differences in the sound frequencies and the noises' waveband are illustrated in Figure 1. Each noise was a minute each in duration and were divided into seconds of 2, so there was a total of 30 recordings of each noise (H1 – H30; NH1 – NH30).

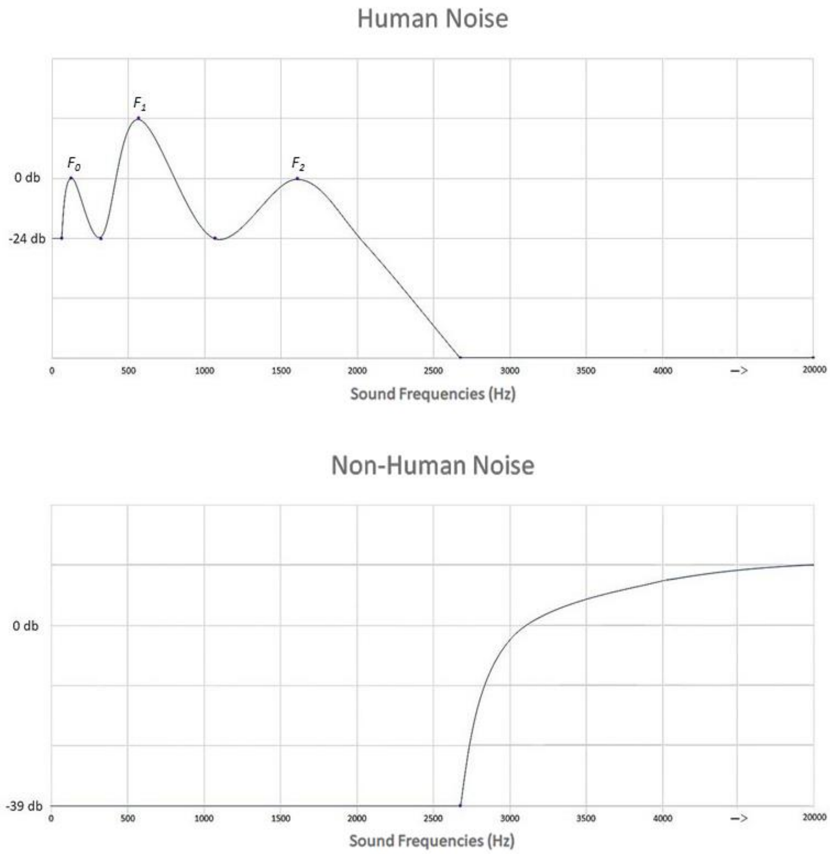

Figure 1. Comparison of the human and non-human noises' frequencies across sound wavebands with formant frequencies.

2.2.3. Final Stimuli

In all recordings for the sentences and the noises created for this task, an equalizer was used. This was with the purpose to remove any unintended background noise, as well as normalizing the recordings to all have the same noise intensity of an average of 70 perceivable decibels. Each end-word from the semantic expectation sentences were embedded in the human and non-human noises with different threshold levels. This signal-to-noise ratio (SNR) was decided through a pilot testing of 10 persons, who listened for the words at different thresholds and indicated with a raising of their hand when they were able to hear the signal in the noise. Two thresholds were set based on the number of correct responses across the SNR band; one which was barely perceivable, with participants giving a correct response rate in 60% of the cases when there was a word embedded in the noise, and one that was more easily perceivable where the word was correctly reported in 90% of its' cases. The latter threshold was included to prime participants for listening for words.

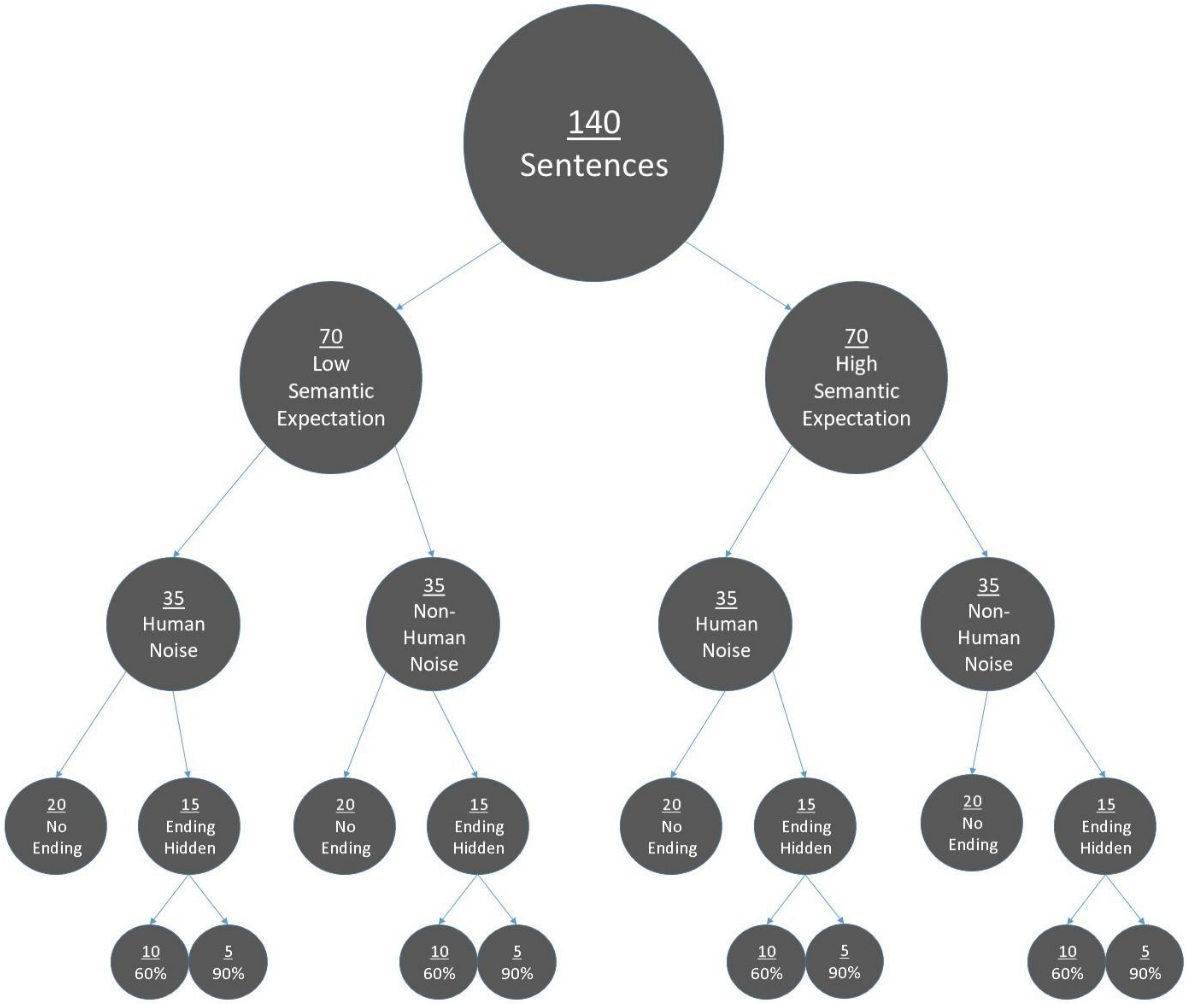

Figure 2. The Partitions of Sentences used in the Listening Task by Type, Noise and Sentence Endings. (The 10/5 dividing of the 60% / 90% is the threshold perceivability of the embedded end-word in its' assigned noise and semantic expectation).

The final distribution of sentences and words across all conditions (i.e. noise, semantic and word-presence/absence conditions) is illustrated in Figure 2. All audio-files were programmed into E-prime version 2.0, along with the correct responses of presence/absence of end-word for each sentence.

2.3. Questionnaires

The following questionnaires were included the study as either part of the screening phase or the experimental phase. A total of seven validity items were included in the experimental questionnaires to ensure that participants answered accurately. These were either items that had been reversed, measured participants' level attention or their honesty.

2.3.1. Screening Questionnaire

Launay-Slade Hallucination Scale (LSHS) (Original version: Launay & Slade, 1981) this experiment used the items from the revised version of the LSHS by Larøi and Van der Linden (2005) to screen participants for hallucination proneness. The LSHS' 16-items are rated on a 5-point Likert scale, and are divided into 5 factors: sleep-related hallucinations, daydreaming, intrusive or vivid thoughts, auditory hallucinations and visual hallucinations. Additionally, the auditory hallucinatory item "I have heard people call my name, and then discovered that there was no one who did," by McCarthy-Jones and Fernyhough (2011) was also included as the final question in the questionnaire (item 27). These were covertly fixed amongst ten more general questions assessing anxiety, personality traits, sensorial perceptions, and quality of sleep. The intention of these questions was to render the purpose of the experiment less obvious and make participants blind to the study's actual aim. The Norwegian LSHS-items had been translated by Kråkvik and colleagues (2015). Demographic questions were also incorporated into the screening questionnaire and included the following: age, sex, field of study, existing hearing impairment or loss, existing psychiatric or neurological diagnoses, and telephone number to establish contact for the second part of the study. Questions regarding participants' hearing and diagnoses were control items for the study's exclusion criteria. Participants' telephone numbers were stored separately to prevent association to any identifying or incriminating personal information. The entirety of this scale had an internal consistency of $\alpha = .909$.

2.3.2. Experimental Questionnaires

A total of five questionnaires were employed during the second part of the experiment following the Signal Detection task to control for various cognitive mechanisms that could act as predictors to false auditory perceptions. The questionnaires were sorted and presented in a way to avoid as much bias as possible as some items might affect the answers on others. The order they are presented in below was the order which they were presented in the study.

The Creative Experiences Questionnaire (CEQ) (Merckelbach, Horselenberg & Muris, 2001): this 25-item (α= .847) scale measures participants' fantasy proneness, i.e. their level of involvement in engaging in fantasies, daydreaming and imaginative imagery. It is a dichotomous rating scale consisting of yes/no questions, and examines factors such as absorption, schizotypal characteristics and dissociation. The scale was back-translated into Norwegian for the purpose of this study.

Encoding Style Questionnaire (ESQ) (Lewicki, 2005): the ESQ is a 21-item scale (α= .779) that was used to assess participants' information processing tendencies and rapidity based on pre-existing schemata versus environmental cues. The total 21 items consist of 15-filler items, while the 6 remaining items are the encoding style items that measures how information is processed based on dependency of internalized schemata and representations. This questionnaire was back-translated into Norwegian.

Aberrant Salience Inventory (ASI) (Cicero, Kerns & McCarthy, 2010): the ASI is a measure of incorrect or unusual assignment of salience, significance or importance to otherwise innocuous stimuli. It is comprised of five factors; feelings of increased significance, heightened emotionality and cognition, impending understanding, and sharpening senses, that all adds up to 29 dichotomous yes/no items (α= .833). The ASI inventory was back-translated into Norwegian for the purpose of this study.

The Cardiff Anomalous Perceptions Scale (CAPS) (Bell, Halligan, & Ellis, 2006): This a 32-item scale (α=.792) developed to measure psychosis proneness and perceptual anomalies (e.g. hallucinations, sensorial sensitivity), and contains sets of different subscales investigating mainly distress, intrusiveness and frequency of these anomalous perceptual experiences. It uses a scoring-system with dichotomous yes/no variables, that pursues a Likert-scale if participants answer 'yes', where three sub-questions measures associations between these erroneous perceptions and participants' level of distress, how distractive it is, and how frequently it occurs from a scale from 'Not at all…' (1) to 'Very…' (5). Colleagues at the University of Bergen translated this scale for an unpublished article. In this study, the CAPS will be used to elaborate upon the LSHS scores of the screened participants to get a clearer insight how they score on psychosis- and hallucinatory items. The CAPS' sub-scale that measure AVHs had a relatively high internal consistency of α= .771, whilst the items measuring psychosis had an internal consistency of α= .664.

Dissociative Experiences Scale – II (DES-II) (Bernstein and Putnam, 1986): the DES-II was created to examine dissociative experiences, which concerns an individual's attachment, or lack thereof, to their immediate surroundings. It consists of 28 items (α= .946) that are rated on a Likert scale ranging from ‘Never’ (0%) to ‘Always’ (100%) and are intended to provide data on a wide variety of types of dissociative traits; from normal dissociative experiences e.g. daydreaming, to more problematic dissociative experiences e.g. dissociative disorders (Bernstein, 1986). The scale was back-translated into Norwegian.

2.4. Apparatus

Adobe Auditions CC was used to create the human and non-human noises, as well as embedding the end-words into the noises and testing the various thresholds during the SNR pilot. An Umarex Laserliner SoundTest-Master measured the noise-intensity (decibels) for the noises. A set of semi-open Beyerdynamic DT 880 Premium 32-ohm HiFi headphones were used during the signal detection task, along with Audioquest DragonFly Black v1.5 USB Digital-to-Analog converter to ensure that the sounds presented during the task were optimally rendered for the specific noise frequencies. The task itself was run on a Windows XP system in E-Prime version 2.0, which was also used to design the task. Additionally, AudioConsole was used pre-testing to ensure that participants’ hearing was within the average hearing-range of their age.

2.5. Procedure

The first part of the study consisted of a screening-phase where participants were collected in lectures and classes and asked to complete the screening questionnaire. The experiment was introduced as a study about auditory perception and personality traits, where participants were selected based on specific traits they displayed in their answers. The anonymity of the questionnaires was particularly emphasised due to the nature of some items.

Following the screening phase, participants were selected based on their high- and low hallucination proneness scores in the LSHS-items and were contacted by phone to arrange for testing at Haukeland University Hospital, Bergen, in one of the audio-labs in the laboratory building. Participants were instructed upon arrival about how the experiment would proceed, with a brief hearing test before the signal detection task, followed by the series of questionnaires. The hearing test was done using a computer-program called AudioConsole that measures a participant’s hearing compared to the average hearing of a person the same age as them. It is a simple listening task, where participants had to press a button each time they heard a signal in either their right or left ear using a headset. If the hearing test was fine, participants proceeded to complete the signal detection task. Here, participants were instructed to listen to the sentences said by either a male or female voice, where the last word of each sentence was either embedded or entirely replaced by a noise. They were asked to listen carefully, as the auditability of the words when present would be very difficult to perceive. Participants were told that their task was to decide whether the last word of each sentence was present or not. Three preliminary trials were run before the actual data recording to ensure the participants had understood the task.

The signal detection task was composed of a series of sequences. Firstly, a visual countdown-method consisting of three black circles decreasing in size would appear to ready participants for the stimuli while also preventing a verbalisation countdown that could potentially prime participants. These circles focused in on a fixation cross that appeared while the sentence followed by the noise were presented to the participants. After the stimuli were presented, the participants were asked to record their answer simply using a ‘yes’ or a ‘no’ button. When the experimental trial was complete, an end-screen would tell participants to refer to the experimenter for further instructions.

After finishing the signal detection task, the participants were asked to complete the questionnaires that examined the cognitive mechanisms that could potentially participants’ performance on the task. The questionnaires were filled out individually, with a brief verbal introduction from the experimenter for each of them to ensure that the pre-determined order was adhered to. When all the questionnaires had been completed, the participants were given a thorough debrief of the study and the study’s true aim was revealed. Participants were also given 150 NOK as compensation for their time. The complete experimental phase of the second part lasted for approximately 1 hour and 15 minutes per participant.

The data was plotted and processed in Statistical Package for Social Sciences (SPSS), version 25, Microsoft Excel 2016 and Statistica 26.

RESULTS

3.1. The Signal Detection Task

Table 1. Main effects and interaction effects (of the repeated measure ANOVA for response bias (β) across the 2x2x2 factorial design (group, noise type, semantic expectation)

	F	***p***
Group	1.460	0.234
Noise	24.075	0.000
Noise*Group	2.925	0.094
Expectation	1.717	0.197
Expectation*Group	1.687	0.201
Noise*Expectation	0.559	0.458
Noise*Expectation*Group	2.209	0.144

The signal detection task used a 2x2x2 factorial design which examined group, semantic expectation, and noise type, all of which has two levels each (group = high proneness & low proneness; semantic expectation = high expectation & low expectation; noise type = human noise & non-human noise). Using a repeated measure ANOVA, there was found no significant triple- or double-interaction effects when examining all conditions using response bias [F (1, 41) = 2.209, $p > 0.05$]. There was no main effect of semantic expectation [F (1,41) = 1.717, $p > 0.05$] nor group [F (1,41) = 1.460, $p > 0.05$], but there was a main effect of type of noise [F (1, 41) = 24.075, $p < 0.001$] on response bias (see Table 1).

As it was hypothesised that there would be observed effects between the high and low hallucination proneness groups on noise type and semantic expectation, planned comparisons was used to examine these specific measures. An independent sample t-test showed no significance in response bias between groups in noise types. There was however a notable trend in the human noise where p=0.078 (High proneness mean = 1.445, Low proneness mean = 2.801; [t (22.510) = -1.850, $p > 0.05$]). A similar trend was observed between groups for the semantic expectation conditions, specifically in the high semantic expectancy conditions where the p=0.075 (High proneness mean = 1.215, Low proneness mean = 2.315; [t (23.711) = -1.863, $p > 0.05$]. When comparing groups across both the noises and semantic expectancy conditions together, a significant contrast in performance was found in the interaction between human noise * high semantic expectancy conditions (High mean = 1.237, SD= 0.763; Low mean = 2.482, SD = 2.174; [t (23.064) = -2.573, $p < 0.05$]), whilst the other conditions remained not significant (see Figure 3).

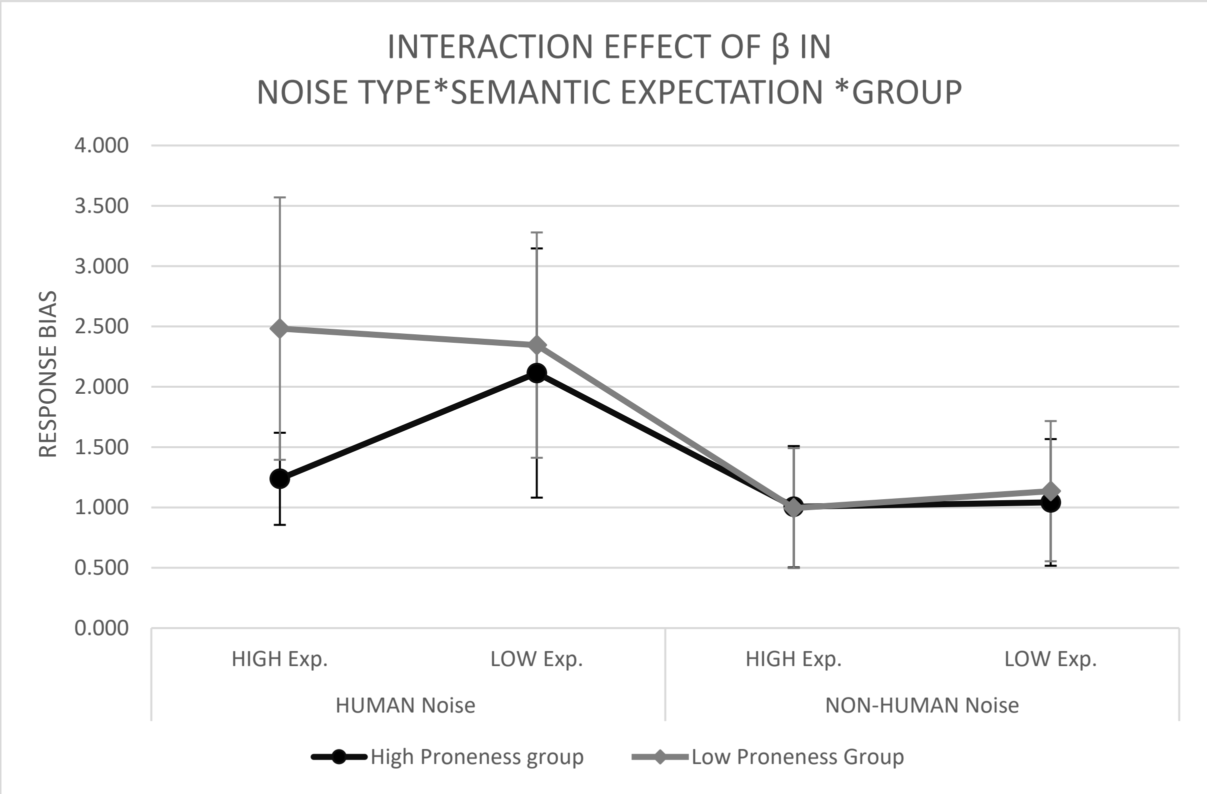

Figure 3. Response bias (β) across all conditions (noise type * semantic expectancy) for both High and Low proneness groups with standard deviations (triple interaction).

Using a repeated measure ANOVA (see Table 2) to examine the significance of false alarms in the 2x2x2 factorial design, there was found no significant triple interaction effect [F (1, 41) = 0.064, $p > 0.05$]. Unlike with response bias there was however a significant double interaction of false alarms in Noise * Expectation conditions [F (1,41) = 13.246, $p < 0.001$]. There was no main effect of semantic expectation [F (1,41) = 3.161, $p > 0.05$] nor group [F (1,41) = 3.722, $p > 0.05$], although there was a trend of group with an almost significant p=0.060. There was also a main effect of type of noise [F (1, 41) = 16.478, $p < 0.001$] on false alarms.

Table 2. Main effects and interaction effects (of the repeated measure ANOVA for false alarms (FA) across the 2x2x2 factorial design (group, noise type, semantic expectation)

	F	***p***
Group	3.722	0.060
Noise	16.478	0.000
Noise*Group	0.158	0.692
Expectation	3.161	0.082
Expectation*Group	0.297	0.588
Noise*Expectation	13.246	0.000
Noise*Expectation*Group	0.064	0.800

Using an independent sample t-test to compare the effects of the separate conditions on performance, it was found that the overall difference in false alarm rates between groups was almost significant, with a *p*. = 0.053 [*t* (35.073) = 2.004, *p*. > 0.05] where the high proneness groups had a higher average rate of false alarms across all conditions (Figure 4).

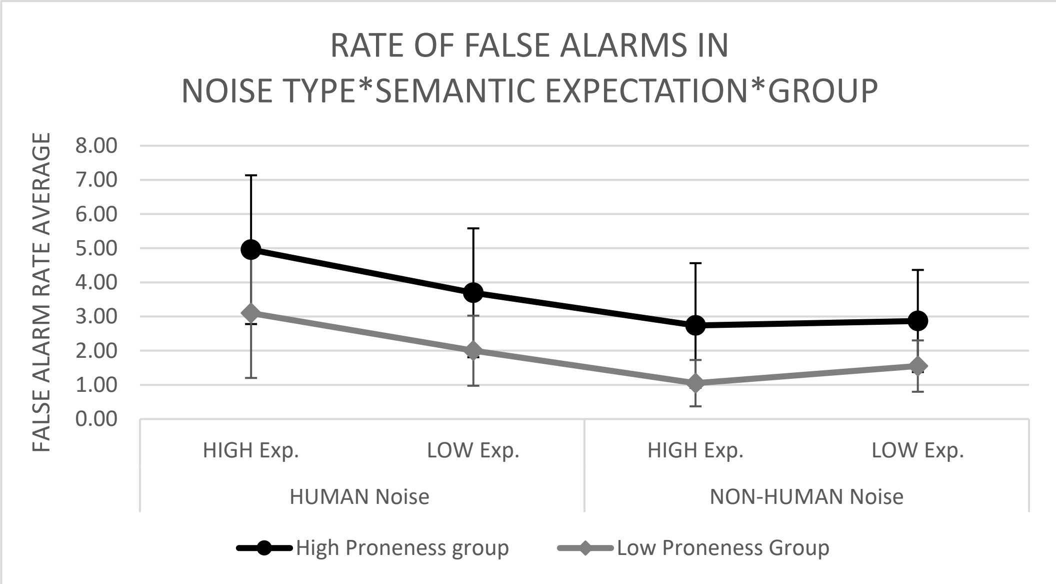

Figure 4. False alarms (FA) across all conditions (noise type * semantic expectancy) for both High and Low proneness groups with standard deviations.

A repeated measure ANOVA (see Table 3) was used to examine the significance of sensitivity. There was no significant triple interaction effect [*F* (1, 41) = 0.838, *p* > 0.05], but like with false alarms there was a significant double interaction of sensitivity in Noise * Expectation conditions [*F* (1,41) = 22.236, *p* < 0.001]. There was no main effect of semantic expectation [*F* (1,41) = 0.879, *p* > 0.05] nor group [*F* (1,41) = 4.075, *p* > 0.05]. Nonetheless, there was an almost significance of p=0.0501 for group, and a significant main effect of type of noise [*F* (1, 41) = 219.390, *p* < 0.001] on sensitivity. There were no significant group differences in sensitivity in neither the human noise (High proneness mean = 1.961, SD = 0.472; Low proneness mean = 2.231, SD = 0.450; [*t* (41) = -1.914, *p* > 0.05]) nor the non-human noise (High proneness mean = 3.096, SD = 0.762; Low proneness mean = 3.456, SD = 0.582; [*t* (41) = -1.718, *p* > 0.05]) (see Figure 5).

Table 3. Main effects and interaction effects (of the repeated measure ANOVA for sensitivity across the 2x2x2 factorial design (group, noise type, semantic expectation)

	F	***p***
Group	4.075	0.050
Noise	219.390	0.000
Noise*Group	0.262	0.611
Expectation	0.897	0.349
Expectation*Group	3.198	0.081
Noise*Expectation	22.236	0.000
Noise*Expectation*Group	0.838	0.365

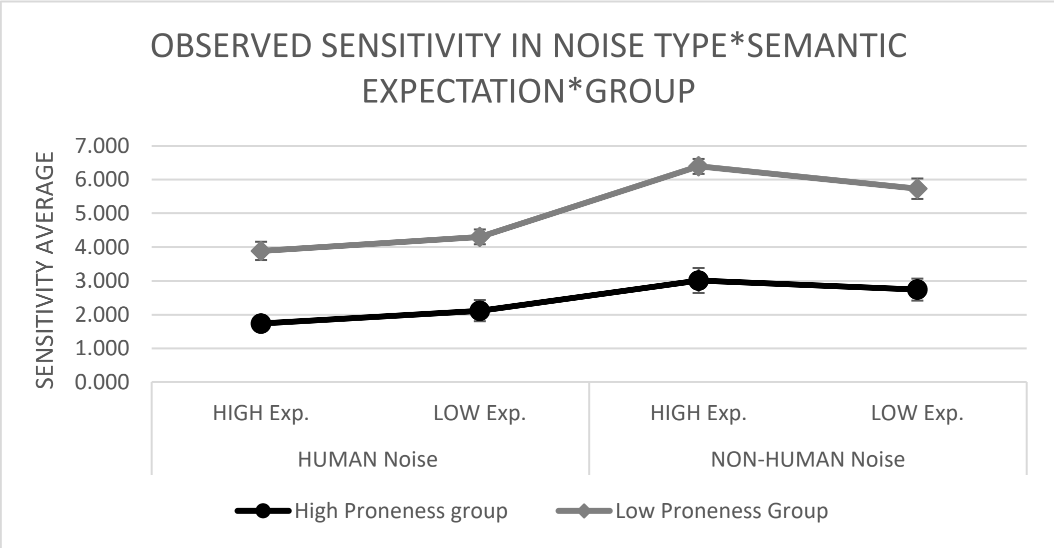

Figure 5. Sensitivity across all conditions (noise type * semantic expectancy) for both High and Low proneness groups with standard deviations.

3.2. Cognitive Predictors

Following the signal detection task, participants were asked to complete several questionnaires measuring various cognitive mechanisms that could potentially predict rate of false alarms and response bias during the task. Using an independent sample t-test, it showed that there were significant group differences across all the scales (see Table 4).

Table 4. Independent sample t-test of group differences in fantasy proneness (CEQ), encoding style (ESQ), aberrant salience (ASI), dissociation (DES-II) & auditory hallucination proneness (LSHS, CAPS_AH).

Scales	Groups	Mean	SD	*t*	df	*p.*
LSHS	*High proneness*	29.478	10.711	9.790	24.487	0.000
	Low proneness	7.000	2.384			
CAPS_AH	*High proneness*	3.261	1.912	5.879	31.742	0.000
	Low proneness	0.650	0.875			
CEQ	*High proneness*	10.391	5.211	4.676	32.208	0.000
	Low proneness	4.700	2.452			
ESQ	*High proneness*	23.913	5.334	3.493	41.000	0.001
	Low proneness	18.200	5.367			
ASI	*High proneness*	15.478	4.785	3.807	41.000	0.000
	Low proneness	9.900	4.800			
DES-II	*High proneness*	45.565	38.884	3.176	41.000	0.003
	Low proneness	17.000	10.804			

A Pearson's correlation analysis also revealed that there was a significant relationship between all the scales, with most of them being highly significant at $p < 0.001$ and $p < 0.01$ levels, with the exception of the ESQ * ASI correlation that was $p < 0.05$ (see Table 5).

Table 5. Pearson's *r.* for fantasy proneness (CEQ), encoding style (ESQ), aberrant salience (ASI), dissociation (DES-II) & auditory hallucination proneness (LSHS, CAPS_AH).

	LSHS	CAPS_AH	CEQ	ESQ	ASI	DES-II
LSHS		.586***	.718***	.428**	.492**	.455**
CAPS_AH	.586***		.668***	.590***	.498**	.609***
CEQ	.718***	.668***		.552***	.689***	.413**
ESQ	.428**	.590***	.552***		.360*	.393**
ASI	.492***	.498**	.689***	.360*		.447**
DES-II	.455**	.609***	.413**	.393**	.447**	

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

When comparing the conditions used in the semantic task with the scales across participants' response bias (β) and rate of false alarms (FA) by using Pearson's *r*, multiple correlations were significant across the scales and conditions (see Table 6). The most prominent cognitive mechanisms were the ESQ and the DES-II, which were significant across all conditions for the false alarm scores. Meanwhile, the most significant condition was the human noise * high semantic expectation condition, where 4 out of 6 scales correlated with response bias (LSHS, CAPS_AH, ESQ & ASI), while 3 out of 6 showed significant correlations for false alarm rates (CAPS_AH, ESQ & DES-II). There were no significant correlations in response bias in the other conditions, and only the LSHS and CAPS_AH showed significant correlations in the human noise * low semantic expectation for false alarms beyond the ESQ and the DES-II.

Table 6. Pearson's *r.* of response bias scores (β) and false alarm rates (FA) on Signal Detection task and fantasy proneness (CEQ), encoding style (ESQ), aberrant salience (ASI), dissociation (DES-II) & hallucination proneness (LSHS, CAPS_AH).

	Human Noise High Expectation		*Human Noise Low Expectation*		*Non-Human Noise High Expectation*		*Non-Human Noise Low Expectation*	
	β	**FA**	**β**	**FA**	**β**	**FA**	**β**	**FA**
LSHS	-0.313*	0.178	-0.138	0.307*	-0.034	0.298	-0.196	0.275
CAPS_AH	-0.331*	0.306*	-0.216	0.353*	-0.122	0.363	-0.107	0.242
CEQ	-0.225	0.228	-0.103	0.24	0.097	0.249	-0.185	0.191
ESQ	-0.393**	0.457**	-0.29	0.435**	-0.073	0.366*	-0.198	0.334*
ASI	-0.304*	0.252	-0.056	0.214	0.154	0.247	-0.165	0.241
DES-II	-0.254	0.425**	-0.163	0.501***	-0.11	0.577***	-0.156	0.478***

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Stepwise multiple linear regression analyses were used to further explore what cognitive mechanisms that could potentially predict the significant response bias scores observed in the human noise * high semantic expectancy interaction condition. The results from the regression analysis indicated that out of all of the scales, only encoding style (ESQ) successfully predicted response bias in the human Noise * high semantic expectancy condition [$R^2 = 0.154$, F (1, 42) = 7.468, $p < 0.01$]. When using the same statistical analysis to see if there was any predictors for false alarm rates in the same conditions, it was just ESQ that showed to have a significant predicting effect [$R^2 = 0.209$, F (1, 42) = 10.824, $p < 0.01$].

Stepwise linear regression analyses were also applied to check for predictors in the scales measuring hallucination proneness in participants. For the LSHS, only CEQ successfully predicted participants' hallucination proneness [$R^2 = 0.515$, F (1, 42) = 43.574, $p < 0.001$]. For the CAPS total score, and when the AVH subscale items were isolated, CEQ and DES-II scores both acted as predictors of hallucination proneness, with the auditory hallucination proneness items (CAPS_AH) showing a slightly more significant effect of its' predictors [$R^2 = 0.580$, F (2, 42) = 27.601, $p < 0.001$] than the CAPS total scores [$R^2 = 0.551$, F (2, 42) = 24.568, $p < 0.001$].

When stepwise linear regression analyses were performed on the other triple-interaction conditions, all variables were excluded from the analyses as none of the scales had no predicting effects on performance during these conditions. Multicollinearity were controlled for in all regression analyses.

DISCUSSION

This study used a signal detection task with a methodology based on Hoskin and colleagues' (2014) study to investigate the underpinning cognitive mechanisms contributing to auditory verbal hallucinations. One of the main aims of the study was to explore the role of bottom-up and top-down processes on the elicitation of hallucination-like experiences (i.e. false alarms) by examining variables such as the effects of semantic expectancy and the impact of two new noises with different sound frequencies on highly hallucination prone individuals compared to low proneness individuals. Another aim of the study was to explore the potential predictors of false alarms and response bias. This study therefore examined cognitive mechanisms such as fantasy proneness, dissociation, aberrant salience and encoding style using questionnaires to investigate whether these predicted performance on the signal detection task and influenced false alarms and response bias scores.

4.1. The Main Effects of Groups, Semantic Expectancy & Noise Types

The two first hypotheses in this study assumed that there would be an overall significant difference between groups on response bias and false alarm scores, where the high proneness group would report a higher rate of false alarms and a more liberal response bias, but a lower sensitivity compared to the low proneness group. The results from the signal detection task showed that there was no significant main effect of group on the task performance. Despite previous studies finding significantly higher response bias and rate of false alarms, there was no overall effect observed between high and low proneness groups. There was however a notable trend of participants in the high proneness group, where they displayed an overall lower sensitivity and higher rate of false alarms than the low proneness group. It is possible that this lack of significant results reflects methodological differences in the signal detection task compared to previous studies such as the noise type, or that the small sample size in this study did not have enough power to have an impact on the main effect of groups. It might also be possible that due to this study's 2x2x2 factorial design that there are specific interactions that are necessary to acquire the desirable significant results.

One of the aims of the study was to test whether specific sound frequencies contributed to the triggering of hallucination-like experiences. In previous studies there appears to be an implicit acceptance of using white noise in signal detection tasks without questioning what characteristics this noise contains that could contribute to the generation of false alarms. Therefore, two new noises (human noise and non-human noise) with different sound frequencies were created. It was hypothesized that the noise types would influence response bias, false alarms and sensitivity, with the human noise causing an increase in false alarms as this was the noise composed from the white noise. There was found a strong main effect of noise across all measures, where the human noise caused a higher rate of false alarms and a lower sensitivity in both groups compared to the non-human noise. All participants had a considerably more conservative criterion in the human noise condition, meaning they all displayed a lesser tendency to report a signal in this noise compared to when listening to the non-human noise which had a more neutral response bias. Based on these results, it would seem reasonable to assume that this difference is due to the presence of human language frequencies in the human noise, versus a lack of them in the non-human noise. When the end-word is embedded in the human noise, it is possible that discriminating the signal from the stimuli becomes considerably more difficult due to the same type of frequencies composing the human noise and the end-word. The human language frequencies might cause similar activations in the auditory cortex as the end-word frequencies do, which cause a decreased sensitivity to the signal's presence, or lack thereof, in the human noise. This might be the cause of the more conservative criterion for all participants as the human noise is more difficult which in turn creates some uncertainty. Furthermore, an increased difficulty in discriminating the end-word from the human noise might be the cause of the increased rate of false alarms and lower sensitivity. Hence, the human noise might require a much greater sensitivity in order to detect or correctly reject the presence of the embedded end-word compared to the non-human noise. These results imply that performance on signal detection tasks are affected by the soundwaves composing the noise used during trials, and that human language frequencies are more likely to activate bottom-up processes and induce aberrant perceptions that possibly contribute to hallucination-like experiences. It might also suggest that it is the presence of formants in white noise that contribute to the generation of false alarms, which is why white noise has been so widely implemented as a stimulus in research on auditory hallucinations in the past.

Based on Hoskin and colleagues' (2014) findings, it was also hypothesised that semantic expectation would affect the performance during the task. Here it was assumed that high semantic expectation would cause a higher rate of false alarms, as well as increase sensitivity in groups. The study did however not show any significant main effects of semantic expectation on performance despite the original hypotheses. There was a small trend of a higher rate of false alarms in the high semantic expectation conditions, which could indicate that high semantic expectancy has an impact if combined with other influential variables such as the human noise. Considering how past studies such as the ones conducted by Hoskin and colleagues (2014), and Vercammen and colleagues (2008; 2010), emphasize the significance of the impact of semantic expectation on false alarms in both clinical and non-clinical populations, the absence of significant results in this study is somewhat surprising. It is nevertheless possible that this study diverges too much from its predecessors in terms of methodology and stimuli. For instance, in the case of Vercammen and Aleman (2010), their semantic expectation conditions could be subjected to some scrutiny. This is mainly due to how their low expectation sentences that did not actually differ from the high expectation sentences except for their end-words which was either embedded or replaced by white noise and therefore difficult to perceive either way. Such a methodology might cause that all their sentences triggers the same level of semantic expectancy, regardless of whether the end-word deviated from each other between conditions as participants were already semantically primed before the white noise stimuli. This could render the level of expectancy almost redundant as it makes it impossible to differentiate one condition from the other, particularly in terms of top-down errors as this study might not actually measure semantic expectancy but rather participants' sensitivity to what the end-words are saying. This might explain why Vercammen and Aleman (2010) had significant data whilst this study did not. However, this study followed the methodology of Hoskin and colleagues (2014) in the way the semantic sentences were framed, where they manipulated their sentence frame to generate false alarms in low versus high expectancy conditions, avoiding the possible methodological issues linked to semantic expectancy in Vercammen and Aleman (2010). Here, it might be possible that the noise stimuli used in the study presented in this paper could have affected the main effect of semantic expectation. It has already been established that noise type, and particularly the human noise, had an impact on the rate of false alarms and response bias, so it might be possible that semantic expectation did not have a main effect due to how the levels of expectancy was perceived in relation to the noises. It is also possible that similarly to the main effect of group, semantic expectation did not independently have a sufficient impact on performance due to the complexity of a 2 x 2 x 2 factorial design. It could therefore be that semantic expectancy only have an effect when paired with the other variables of the study.

4.2. The Triple-Interaction Effects

Out of the main effects in noise type, semantic expectation and group, only the human noise showed to have a significant impact on the performance during the signal detection task. This indicates that aberrant bottom-up processes play an important role in false alarm generation. There were however weak trends for both the groups and semantic expectancy, which might suggest that whilst these variables do not reflect any main effects on the performance on the signal detection task, they could contribute to an interaction effect across conditions. One of the aims of study was to examine these interaction effects by investigating the interplay of top-down and bottom-up processes proposed by Waters and colleagues (2012). Deriving theories off their model, a triple-interaction between groups, noise type and semantic expectation was expected. When the triple-interactions between group, semantic expectancy and noise type was investigated for however, there was found no significant results across the overall score for response bias, false alarms nor sensitivity contrary to the original hypothesis. Considering the diverse nature of the conditions and the past results for the main effects where only the noise type showed any significant data, this might not be all that surprising due to the triple-interaction analysis reflecting the overall score of a large combination of very different variable combinations and conditions. Because of this, the triple-interactions needed to be examined closer and on a more individual level with different combinations of variables across multiple conditions.

When the triple-interactions were investigated for different combinations of variables using planned comparisons, it was found that there was a significant difference in response bias between groups for the human noise * high semantic expectation conditions. Here, the high hallucination proneness group displayed a significantly more liberal criterion, meaning that they had a greater tendency to report a signal in the noise than the low proneness participants, which were considerably more conservative in their assessments during these specific trials. This coincides with the model by Waters and colleagues (2012), who proposed that AVH generation is dependent on an interaction between hyperactivity in the auditory cortex (bottom-up) and modes of cognitive control/error-processing (top-down). These modes of cognitive control are in theory affected by errors in signal detection and inhibition deficits, which could potentially cause aberrant processing of high semantic expectancy in the combination with the human noise. This assumption, along with a disposition towards towards hallucinatory experiences, could cause the arising of what Waters et al. (2012) describes as complex, multidimensional experiences. The nature of the auditory stimuli causing aberrant bottom-up and top-down processes leading to erroneous perceptions can be speculated. For the top-down processes, the level of semantic expectation only appears to have an impact on participants' performance when it is combined with a noise type with human formants. Further, the human noise only appears to cause significant group differences when combined with a high level of semantic expectancy, but not a low level of expectancy where high hallucination prone participants did not differ from the low proneness participants. High semantic expectancy might therefore have an important impact in contributing to a more liberal criterion in highly hallucination prone participants. This might happen through semantic priming caused by the highly expectant sentences when there is an increased difficulty in determining the presence of the end-words from the human noise due to the similar human language frequencies. It might mean that whilst noise type has a greater overall impact on response bias, a high semantic expectancy contributes to the significant group difference between the high proneness group and the low proneness group in the human noise. If considering these results in regard to the signal detection theory (Bentall & Slade, 1985), it could be assumed that if the noise type is the one that cause hyperactivity in auditory neural pathways then high semantic expectancy might be the determining factor for misattribution of salience to irrelevant stimuli in hallucination prone individuals. It might be that pattern recognition is activated at a certain threshold of semantic priming and that inhibition deficits cause the mistakenly perceived external attributions to be preceded by these errors and cause the generation of false alarms in ambiguous noise.

This triple-interaction effect that was observed in response bias for the group * human noise * high semantic expectation interactions were not reflected in false alarm rates or sensitivity. Both of these measures however showed that there were significant double-interaction for noise type and semantic expectation. An interaction of these two conditions indicates that the rate of false alarms and sensitivity is largely dependent on what variables are presented together. For false alarms, this is apparent in the overall scores across all conditions which shows the lowest rate of false alarms in the non-human noise * high semantic expectations and the highest rate in the human noise * high semantic expectation for all participants. For sensitivity, the interaction is inverted from false alarms, in the way that the highest sensitivity scores were in the non-human noise * high semantic expectation and reduced sensitivity scores in the human noise * high semantic expectation conditions. The low sensitivity scores and high false alarm rates in the human noise * high semantic expectation conditions augment the argument that the human noise makes it difficult to differentiate noise from end-word stimuli for both groups due to the human language frequencies. Interestingly, high semantic expectation act in this case both as a cause of a higher rate of false alarm due to priming in the human noise where the signal is difficult to differentiate from the noise, but also a cause of hits and correct rejections in the non-human noise where the signal is more easily detected in the noise due to how the noise type is the opposite of the signal.

4.3. The Cognitive Predictors

After the signal detection task, the participants completed a series of questionnaires which purpose was to measure other cognitive mechanisms that might act as predictors for the performance on the task. In this study, the mechanisms that were examined was aberrant salience (ASI), encoding style (ESQ), fantasy proneness (CEQ), and dissociation (DES-II), in addition to a further exploration of the AVH proneness reported in the LSHS-screening questionnaire by using the Cardiff anomalous perception scale (CAPS). Independent t-test showed there was a highly significant difference between high- and low proneness participants in their scores on all the questionnaires, indicating that the groups differed from each other on more than just hallucination proneness. The high proneness group scored overall higher across all scales, indicating they had an increased level of fantasy proneness, aberrant salience, dissociation and a more internal encoding style. Correlation analyses also revealed that all scales are strongly correlated with each other, which means that some associations can be assumed. More specifically, it suggests that these mechanisms might overlap or interact on a certain level, which would make sense considering all of these mechanisms process and interprets the external environment and creates a perceptual reality through what is most likely similar internal cognitive systems. Further, it was found that some of these mechanisms had a significant correlation with response bias and false alarms scores. The condition of the signal detection task which had the most significant correlations was the human noise * high semantic expectation, where ESQ was highly significant with both response bias and rate of false alarms, and DES-II was highly significant with false alarm rates. ASI and LSHS also correlated with response bias and CAPS correlated with false alarms in this condition. If taking these correlations and also the significant group differences across all the scales into consideration, it could suggest that these mechanisms might influence the performance during the task.

The final hypothesis in this study was of a more exploring nature and examined whether any of the cognitive mechanisms measured using questionnaires predicted performance on the signal detection task. A stepwise linear regression analysis showed that out of all the mechanisms, only one cognitive mechanism predicted the performance on the task in this study and that was the ESQ. Hallucination prone participants scored significantly higher on the ESQ compared to the low proneness group, which means that they had a much more internalized encoding style. In earlier literature it has been established that an internal encoding style is a fast type of perceptual processing that is prone to misattribution errors and "split-second illusions" by imposing imperfect or wrongly perceived schemata onto stimuli (Lewicki, 2005). Here it would seem reasonable to compare "split-second illusions" to false alarms, and to consider the possibility that an inability to distinguish meaningful signals from insignificant noise might be due to a failure to inhibit internalised representations being imposed onto meaningless, ambiguous noise. This is in line with and could also be incorporated into one of the previous argument in this paper, where it was assumed that noise type might cause hyperactivity in auditory neural pathways and that high semantic expectancy might be a determining factor for misattribution of salience due to pattern recognition and inhibition deficits. In the case of the significance of the triple interaction in response bias, a fast, internal encoding style might mediate the relationship between the aberrant auditory signals caused by the human language frequencies in the human noise, and the misattribution of salience due to the high semantic expectancy, by imposing schemata onto the noise when the sentence generates a certain level of expectancy. Added the difficulty in distinguishing the signal and the noise due to the human language frequencies, and inhibition deficits in hallucination prone individuals, this might contribute to a higher rate of mistakenly perceived external attributions and thereby an increase in false perceptions and false alarms.

It remains uncertain why ESQ was the only predictor of response bias in this study. For instance, these findings are contradictory to the ones found by Merckelbach and van de Ven (2001) where they argued that fantasy proneness was a better predictor for response bias and false alarms than hallucination proneness. Fantasy proneness was however not found to be a significant predictor of participants' performance on the signal detection task in this study. It is possible that the results were not significant due to methodological proceedings, as Merckelbach and van de Ven (2001) employed the use of an adapted version of Barber and Calverely's (1965) White Christmas test where they in addition used white noise for the listening task. Firstly, they used a famous song which participants were exposed to prior to the task which participants had to confirm being familiar with. If participants are familiar with the song and they have been played the song before the experiment, it is likely that this would cause a high level of expectancy. As seen in the study in this paper, when participants have a high level of expectancy of the signal in a combination with being exposed to ambiguous noise such as white noise in which they are told the signal might be embedded, it is a lot more likely to cause a higher rate of false auditory perceptions. Further, it is uncertain how a song could affect the rate of false alarms compared to semantically expectant sentences, as they might appeal to or trigger different pathways and structures in the phonetic memory. The rate of false alarms might also be more related to participants' memory of the lyrics and melody when they are expecting a song hidden in white noise, rather than unfamiliar sentences with high semantic expectancy which are imposed upon by internalised representations. Secondly, they employed four questionnaires which was intended to predict the performance on their task. However, since they used the overall LSHS scores rather than the auditory items, they found that fantasy proneness was a better and only predictor than hallucination proneness. This relates back to the argument about an inconsistent use of the LSHS, where a lot of studies use all its' items. This could be considered too unspecific when examining auditory hallucinations in tasks like this one by Merckebach and van de Ven's (2001) as LSHS covers a broader spectrum of hallucinations and abnormal experiences. To illustrate, when examining the dataset in these preliminary results, the stepwise regression revealed that out of the LSHS total scores and the auditory hallucination subscale item scores, it was only the total LSHS scores that predicted participants' CEQ scores, [R2 = 0.515, F (1, 42) = 43.574, $p < 0.001$]. When the same stepwise linear regression was used with the ESQ scores as the dependent variable, it was the LSHS' AVH scores that was the only predictor, [R2 = 0.210, F (1, 42) = 10.869, $p < 0.01$]. This could suggest that the association found by Merckebach and van de Ven's (2001) might have been influenced by other items in the LSHS. This analysis of the total score versus the AVH-specific items could offer some support for the argument that a stricter use of subscales and focused items from such scales as the LSHS when researching specific forms of hallucinations is necessary in order to get more consistent results across papers. Finally, it would therefore appear that Merckelbach and van de Ven's (2001) differed too much in its methodology from this one, which why the findings of predictors in this study was inconsistent with those of Merckelbach and van de Ven (2001).

For the mechanisms that were not significant predictors in this study, i.e. fantasy proneness, dissociation and aberrant salience, it might be that they have a more indirect influence by on the performance during the signal detection task. This could be a possibility as these mechanisms showed to be significantly related to the response bias and false alarms rates in the correlational analyses, indicating they might have more of an indirect impact on shaping aberrant perceptions of stimuli, and possibly affect participants' performance by overlapping and interacting with top-down and bottom-up processes that are more directly involved. It might be a reasonable assumption, as both fantasy proneness and dissociation predicted hallucination proneness in participants. Mechanisms such as this could therefore be more discreet in how they create erroneous perceptions of auditory stimuli.

4.4. Further Interpretations & Implications

From the present study, it is impossible to infer any causality of the top-down and bottom-up processes in the generation of false alarms. Nonetheless, it does make it possible to make some assumptions about the specific mechanisms involved in the generation of false alarms, and perhaps further the research on this phenomenon. More importantly, this study presents some supporting evidence for the signal detection theory (SDT) as participants with high hallucination proneness showed a reduced capability of distinguishing meaningful signals from insignificant noise, and thereby reported hearing signals even while they were not present. Interestingly however, hallucination prone individuals did not display any bias in their confidence of perceptual judgements, contrary to claims Burgess and colleagues (2005), as they did only differ from the low proneness group in response bias in the human noise * high semantic expectation conditions. This could indicate that criterion depends on what type of stimuli is being processed and under what conditions these are presented in. For the two main theories composing the SDT, it is unlikely there was any involvement of reality testing, mainly because encoding style showed to have predictive impact on performance during the signal detection task. This indicates that it is not a matter of mistaking imaginary events as real, but rather an inaccurate imposing of internalised representation due to inaccurate perceptual processing and intentional inhibition deficits. It is therefore more likely that cognitive mechanism such as encoding style in combination with high semantic expectation cause false alarms and a less conservative criterion in conditions where the auditory stimulus contain human language frequencies that cause activations in the auditory cortex that results in a decrease of sensitivity to the presence of a signal in the noise. The second theory that is part of the SDT, the source monitoring hypothesis, was not relevant in this study as source monitoring is a form of memory bias and therefore not measurable in this online task.

The question remains whether false alarms is the same as AVHs, or whether the signal detection task measure something else entirely. This study shows that while hallucination proneness did not have a significant main effect, there was a significant group difference in the specific triple-interaction condition. Based this particular observed difference in the group * human noise * high semantic expectation, it would appear that hallucination proneness is the main differentiating factor causing the observed effects of noise type and semantic expectation as they also had a significantly higher ESQ score, which indicates an internal encoding style which was a predictor for their performance. Moreover, this is solidified that the high hallucination proneness group did not differ in criterion from the low hallucination proneness group when presented with the non-human noise. This might imply that false alarms may be a form of auditory verbal hallucinations, as the high hallucination prone participants differed so significantly from the low proneness participants when trialled with the human noise combined with the high semantic expectancy.

4.5. Limitations & Future Research

This study had a couple of limitations that should be taken into consideration and remedied in future research on the White Noise paradigm and signal detection tasks. The main limitation with this particular experiment was its sample size. It might be that some of the effects and interaction that were not significant can be attributed to not enough power in the sample of 43 participants, as it was estimated through a power analysis prior to the beginning of the study that a total of 88 participants was necessary to achieve the desirable results. These results are also preliminary, so a larger sample might affect the results for both the main effects and the predictors found in this study. Another possible methodological limitation to keep in mind with these specific types of studies is one presented by Waters and colleagues (2012). They stated that a typical issue with cognitive studies of AVHs such as this is that they can be restrictive in their ability to fully employ the theoretical constructs of interest. Simply put, they question whether studies measure what they intended to measure, as experiments sometimes fail to properly translate theoretical aspects into measurable variables. In this study the intention was to measure the processes involved in the generation of auditory verbal hallucinations. It is debatable whether false alarm are actually auditory hallucinations. The results in this study do however suggests that hallucination proneness as a group variable is a good indicator of the response bias, and that high proneness individuals have a consistently more liberal criterion than low proneness individuals when exposed to the right noise type and semantic priming. It is a considerable amount of brain systems involved in the generation in auditory hallucinations, and this task only measures the cognitive level of this phenomenon. A suggested solution to uncover whether false alarms are the equivalent to auditory hallucinations is to use cross-disciplinary work and engage in multiple levels of explanation (Hugdahl & Summer, 2017) to identify similarities and disparities in mechanisms, processes, systems, characteristics and traits.

The signal detection task developed for the purpose of this study has demonstrated the value of a 2x2x2 factorial design when examining a multidimensional cognitive model to investigate auditory hallucinations. In particular, it has demonstrated the importance of specificity of human language frequencies and how these interact with top-down processes in the generation of false perceptions. Future research should investigate other cognitive mechanism that could possibly affect auditory perception such as e.g. suggestibility and emotion, and possibly employ a wider field of explanations which engage in multiple cross-disciplinary fields to properly understand how auditory hallucinations arise in certain individuals. It is also recommended that studies employing the use of signal detection tasks to investigate AVHs should utilize noise types similar to this study which discriminates between specific sound frequencies. Other recommendations for future studies include a clear distinction between high and low semantic expectancy if using sentences during the task, and if participants are screened prior to testing to use questionnaire items specific to auditory hallucinations to avoid confounding variables. The signal detection task developed for this study could also be a valuable tool to assess hallucination proneness in persons independent of self-measure questionnaires which are often prone to be affected by social desirability, exaggerations and emotional states of the participants. This is an option for future research using hallucination proneness as a measure or a grouping variable, but the task can also be applied to clinical practice where it could be used as an indiscriminate measure for assessment of positive symptomatology. Finally, as these results were preliminary, the next steps should be to employ the study on a grander scale with more participants and examine whether these results are replicated in clinical samples with AVH symptoms. This might give some indication of shared cognitive mechanisms across populations and broaden the understanding of the processes involved in the generation of false perceptions

CONCLUSION

This study examined the effects of top-down and bottom-up processes on the generation of false auditory perceptions in a non-clinical sample. It employed the use of an adapted signal detection task where high- and low hallucination prone groups were tested using sentences with either high- or low level semantic expectancy (top-down processes), as well as two new noise types derived from different sound frequencies in white noise (bottom-up processes). Additionally, cognitive mechanisms that could act as predictors on task performance was measured. The main finding of this study was the significant difference in response bias that was observed between the high proneness and low proneness groups when they were exposed to trials where the human noise and the high semantic expectancy conditions were paired together. Here, high hallucination prone participants displayed a significantly more liberal criterion than the low proneness group. Further, encoding style was found to predict the response bias in the triple-interaction between group, semantic expectancy and noise type. Based on these findings, it was assumed that a potential cause of false auditory perceptions and how they arise could be due to an interaction between noise containing human language frequencies that cause hyperactivations in the auditory cortex, and semantic priming which cause misattribution of salience due pattern recognition and inhibition deficits. These factors might possibly be mediated by an internal encoding style, which could be imposing internalised representations onto the complex auditory stimuli. These results offer strong support for the cohesive integrated cognitive model proposed by Waters and colleagues (2012), where they theorised that generation auditory hallucinations in hallucination prone persons are due to a combination of various top-down and bottom-up processes. Furthermore, this study demonstrates that the signal detection task is an efficient tool for measuring response bias, sensitivity and false alarms. With the additional variable of specific noise types, the signal detection task might have become even more sensitive to detecting such false auditory perceptions in hallucination prone individuals.

In conclusion, the aetiology for AVHs remains unclear, but this study offers tentative evidence for an interaction between cognitive top-down and bottom-up processes that could potentially contribute to their generation. In order to make progress in this particular field of study, more research need to closer examine the effects of sound frequencies and semantic expectation as these appear to be the two main determining external factors in the generation of false auditory perceptions.

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APPENDIX A – REK APPROVAL

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 persepsjonene 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 hypoter 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 tilbakemeldingen som besvarer komiteens spørsmål og merknder på en god måte.
I informasjonsskrivet bør begrepene "autidiv" 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