Olfactory hallucinations in a population-based sample

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ABSTRACT

Olfactory hallucinations referring to olfactory perceptions in the absence of chemical stimuli, occur in non-clinical and clinical populations. Few studies have investigated their prevalence in the general population and little is known about factors triggering and maintaining them such as substance use, severe life events, and mood. We analyzed self-report data from 2500 community dwelling Norwegians, aged 18-96 years, for occurrence of olfactory hallucinations and co-occurring hallucinations in other modalities (auditory, visual, tactile). Analyses included age, sex, self-reported symptoms of depression and anxiety, mental health status, and experience of severe life-events. The results show that 4.2% (95% CI 3.5-5.1%) reported having experienced olfactory hallucinations, and 56% of individuals experiencing olfactory hallucinations also reported these in combination with hallucinations in other modalities. Prevalence varied significantly in terms of age and sex, in that olfactory hallucinations were most frequently reported by young individuals and females. Self-reported symptoms of anxiety and experience of stressful life events were significantly associated with olfactory hallucinations, suggesting that experiencing olfactory hallucinations may negatively affect functioning and may increase the likelihood of developing psychopathology. Findings underline the need to continue to examine olfactory hallucinations albeit with a more comprehensive assessment in order to increase knowledge on this experience.

1. Introduction

Hallucinations are sensory perceptions occurring in the absence of corresponding sensory stimuli. Although considered a core feature of psychosis, studies point to their occurrence and relevance in other clinical groups (Aleman & Larøi, 2008) and in healthy individuals (Johns et al., 2014; Krakvik et al., 2015; Nuevo et al., 2012; Waters, Blom, Jardri, Hugdahl, & Sommer, 2018). Understanding the underlying mechanisms of these different types of hallucinations, as well as their consequences on daily life, could aid improving the lives of those affected (Johns, 2005; Waters et al., 2018). While auditory

hallucinations (and to a lesser extent, visual hallucinations) have been frequently studied in the general population, much less is known about olfactory hallucinations.

The sense of smell is increasingly recognized as an important factor for well-being and quality of life (Croy, Nordin, & Hummel, 2014; Miwa et al., 2001; Rochet, El-Hage, Richa, Kazour, & Atanasova, 2018). In the somatic/olfactory literature, a differentiation is commonly made between qualitative and quantitative olfactory functions. Qualitative olfactory dysfunctions include *olfactory hallucinations*, also termed *phantosmia*, referring to an odor sensation without a present stimulus (i. e., a person perceives the smell of an orange in the absence of any orange

or orange scent). Although both terms are often used interchangeably, some researchers differentiate between olfactory hallucinations lasting a few seconds and phantosmia lasting longer (D. Leopold, 2002). The other qualitative dysfunction is *parosmia,* indicating a distorted perception of an odor (i.e., smelling an orange evokes the perception of something rotten). Quantitative olfactory functions are commonly differentiated into *sensitivity* referring to the ability to detect an olfactory stimulus and *identification* referring to a person's ability to identify an olfactory stimulus (Frasnelli et al., 2004).

Prevalence rates and the association between qualitative and quantitative olfactory functions are still a matter of debate. One reason for this relates to assessment methods with objective methods only being available for quantitative functions, while qualitative olfactory functions are exclusively based on self-reports. Additionally, both qualitative and quantitative self-reported functions are known to be biased. Although specificity for quantitative smell function has shown to be high in large population-based studies, indicating that individuals with a normal sense of smell tend to accurately report no dysfunction, sensitivity is as slow as 20-30%, suggesting that individuals with an impaired sense of smell are unaware of the problem (Lotsch & Hummel, 2019; Murphy et al., 2002; Wehling, Nordin, Espeseth, Reinvang, & Lundervold, 2011; Yang & Pinto, 2016). Qualitative dysfunctions have been shown to be overreported, at least by populations from chemosensory clinics (Gent, Goodspeed, Zagraniski, & Catalanotto, 1987).

There is no objective, accurate diagnostic measure to assess olfactory hallucinations. Landis et al. (2010) raised the issue that standardized, more systematic questioning would provide meaningful scores on qualitative olfactory dysfunctions. So far, assessment occurs either during a clinical interview or as part of a questionnaire (often using a single item question such as "Do you sometimes experience a particular odor even though nothing is there?"). In the clinical setting, more details may emerge, and a verification may be followed up with further qualitative questions. Response formats in questionnaires vary from a "*yes/no*"-format to scale-formats with endpoints like "*never*" to "*six to seven times a week/always*" (Bainbridge, Byrd-Clark, & Leopold, 2018; Ohayon, 2000). This may contribute to variation in prevalence rates.

Studies from chemosensory clinics estimate prevalence rates of 11-25% for olfactory hallucinations occurring after sinonasal diseases, upper respiratory infections, head trauma, epilepsy, migraine/headache, neurodegenerative diseases, and advancing age (Bramerson, Nordin, & Bende, 2007; Coleman, Grosberg, & Robbins, 2011; Landis & Burkhard, 2008; Landis, Konnerth, & Hummel, 2004; Nordin et al., 1996; Reden, Maroldt, Fritz, Zahnert, & Hummel, 2007). Leopold (2002) describes the classic case presenting with olfactory hallucinations as "*a woman between 15 and 30 years of age with an episode of odor perception the individual thinks is real but others do not appreciate. It resolves spontaneously with no aftereffects*" (p. 613). He describes that in the long-term a similar experience may occur within a month, followed by increasing frequency, longer duration, potentially lasting years. To date, duration of the actual olfactory hallucination episodes and the duration across lifetime is rarely systematically addressed. Regarding the former, Sjolund and colleagues (2017) reported olfactory hallucinations mainly to be fleeting (39%) or lasting a few minutes (43%). The existing longitudinal studies on olfactory hallucinations across lifetime report improvement/disappearance of olfactory hallucinations in 30-64% of cases, no change in 39-60%, and deterioration in 5-10% (Landis & Burkhard, 2008; Reden et al., 2007).

In psychiatric disorders, olfactory hallucinations are reported in patients with depression (Croy, Yarina, & Hummel, 2013), bipolar disorder (Baethge et al., 2005), and schizophrenia (Langdon, McGuire, Stevenson, & Catts, 2011; Stevenson, Langdon, & McGuire, 2011). Occurrence rates range from 13-17% in depression and bipolar disorders to 13-35% in schizophrenic and schizoaffective disorders (Baethge et al., 2005; Langdon et al., 2011). Compared to other modalities, olfactory hallucinations appear to be (one of) the least common hallucinations (Baethge et al., 2005; Lewandowski, DePaola, Camsari, Cohen, & Öngür,

2009). This could be related to the fact that rating scales frequently group olfactory hallucinations together with somatic, tactile, or gustatory hallucinations (Lim, Hoek, Deen, Blom, & Investigators, 2016). Langdon et al. (2011) underlined that an evidently high proportion of patients with schizophrenia report olfactory hallucinations when these are explicitly assessed. The only large scale study (n > 13000) investigating associations between olfactory hallucinations and mood (anxiety, depression, and bipolar disorders) and adjustment disorders, reported associations of anxiety, bipolar, and adjustment disorders in participants experiencing frequent (at least once a week) and infrequent (once a month or less) olfactory hallucinations (Ohayon, 2000). An association with depression was only reported when infrequent olfactory hallucinations occurred. The author suggested that olfactory hallucinations may be triggered by psychoactive substances or medication, rather than being a symptom of psychiatric disorders. Longitudinal studies focusing on olfactory hallucinations indicate that these may help to identify psychosis-prone individuals within a risk group (Kwapil, Chapman, Chapman, & Miller, 1996), and that these hallucinations are associated with an earlier age of psychosis onset (Lewandowski et al., 2009), although this has not always been confirmed (Langdon et al., 2011).

Studies investigating prevalence rates for olfactory hallucinations in the general population are scarce. The few existing population-based epidemiological studies report prevalence rates varying between 5-14.5% (Bainbridge et al., 2018; Ohayon, 2000; Rawal, Hoffman, Bainbridge, Huedo-Medina, & Duffy, 2016; Sjolund, Larsson, Olofsson, Seubert, & Laukka, 2017). In by the far largest study (Ohayon, 2000), the prevalence rate of 14.5% for olfactory hallucinations during daytime are further differentiated into *frequent* (at least once a week; prevalence rate 2.4%) and *infrequent* (once a month or less; prevalence rate 12.1%). Two recent studies reported 12-month prevalence rates between 6-6.5% in community-dwelling adults aged 40 years and older (Bainbridge et al., 2018; Rawal et al., 2016). A lower rate of 4.9% 12-month prevalence rate was reported in a Swedish study including individuals aged 60-90 years (Sjolund et al., 2017).

These epidemiologic studies consistently show that olfactory hallucinations occurred more often in women (Bainbridge et al., 2018; Ohayon, 2000; Sjolund et al., 2017). Other sociodemographic and somatic factors that are associated with a higher prevalence of olfactory hallucinations are younger age (< 40 years), low socio-economic status, poor self-reported health status/cardiovascular risk, head injury, and persistent dry mouth symptom (Bainbridge et al., 2018; Sjolund et al., 2017). Factors such as ethnicity, education, smoking, and alcohol use were not clearly associated with olfactory hallucinations.

Despite the above findings, the prevalence of olfactory hallucinations and associated factors are still under-researched. Replications in large population-based samples including factors known to be associated with hallucinations in other modalities, are needed. Linscott and van Os (2013) summarized that psychotic-like experiences (including hallucinations) are highest in young individuals (below the age of 40 years), with low education, who have been exposed to alcohol and drugs, and who have experienced stressful and traumatic events.

The primary aim of this study was to investigate the prevalence of olfactory hallucinations in a large Norwegian population-based sample that included a wide age-range (18-96 years). Secondly, associations between olfactory hallucinations and age, biological (substance and alcohol use), social (self-reported severe, stressful life events), and emotional factors (self-reported symptoms of depression and anxiety) were investigated. Finally, the experience of olfactory hallucinations in combination with hallucinations in other sensory modalities was investigated.

2. Methods

2.1. Participants

A representative sample (8000 individuals) of the Norwegian

population between 18-96 years of age were randomly selected by the Central Bureau of Statistics in Norway and were invited to take part in the present study. Inclusion criteria were that they were (1) born, raised, and currently living in Norway and (2) able to speak Norwegian. Individuals were asked to complete an extended version (Laroi, Marczewski, & Van der Linden, 2004; Laroi & van der Linden, 2005) of the Launay-Slade Hallucinations Scale (Launay & Slade, 1981), the Hospital Anxiety and Depression Scale (HADS) (Zigmond & Snaith, 1983) as well as questions on demographics. Of the 8000 invited individuals, eleven refused to participate and 169 could not be reached. Of the remaining 7820 individuals, 2533 completed the entire questionnaire (and of these 2533, 2500 answered the question regarding olfactory hallucinations). The study was approved by the Regional Committee for Medical Research Ethics in Central Norway (REK Central) and executed according to the Code of Ethics of the World Medical Association (Declaration of Helsinki). All participants gave their informed consent prior to inclusion in the study.

2.2. Launay-Slade Hallucinations Scale

Assessment of hallucinations was based on a Norwegian translation of an extended version of the Launay–Slade Hallucinations Scale (Laroi et al., 2004). Compared to the original version (Launay & Slade, 1981), additional items assessing hallucinations in other modalities (visual, tactile, olfactory) were included. Olfactory hallucinations were assessed with the statement "I have experienced a particular odor even though there was nothing there". Response categories were "certainly does not apply to me", "possibly does not apply to me", "uncertain", "possibly applies to me" or "certainly applies to me". Since existing studies base their analyses on a "yes/no" response format and we aimed to replicate such findings, the category "certainly applies to me" was taken as an indicator of olfactory hallucinations. We wanted to be sure that that participants actually had experienced an olfactory hallucination. Prevalence rates and all subsequent analyses are based on this category.

2.3. Depression and Anxiety

The Hospital Anxiety and Depression Scale (HADS) is a fourteen-item questionnaire that assesses self-reported symptoms of anxiety (7 items) and depression (7 items) (Zigmond & Snaith, 1983). Each item is rated on a four-point Likert scale, generating a total score ranging from 0 to 21 for each subscale, with higher scores indicating more self-reported symptoms of depression and anxiety. A cut-off point of > 7 indicative of anxiety or depression for either individual subscale, was applied in the analyses (Bjelland, Dahl, Haug, & Neckelmann, 2002).

2.4. Statistical methods

Descriptive statistics were used to examine group characteristics with regard to sex, age, and health factors. The prevalence of olfactory hallucinations was estimated using separate logistic regression analysis, including the 95% confidence interval (95% CI) for the odds ratio. Factors established in the literature to be associated with hallucinations in any modality in non-clinical groups and available in the questionnaire consisted of information on socio-demographic data (age, sex, educational level), self-reported symptoms of anxiety and depression, self-reported mental health, experience of severe life events (i.e., experience of danger/accident; bullying/humiliation) and use of illicit drugs. In a second step, we included significant variables into a multivariate logistic regression model, entering one variable at a time. When variables no longer had a statistically significant association, they were excluded. This variable selection method for building logistic regression models invalidates the use of p-values due to multiple testing. The p-values from the final model do not reflect that each covariate has already been tested in univariate regression, and in the stepwise selection procedure. Therefore, we chose to report regression results as odds ratios

(OR) with a 95% CI. Analyses were performed using SPSS.

3. Results

In the sample, 4.2% (n = 106, *CI 3.5-5.1*) of individuals reported the experience of being certain of their experience of olfactory hallucinations. This number was the basis for subsequent analyses. One-hundred and forty-nine (6%, *95% CI 5.1-6.9*) reported that they possibly experienced olfactory hallucinations. The frequency distributions of demographic characteristics for individuals reporting and not reporting olfactory hallucinations are summarized in Table 1.

The largest age group in the study consisted of individuals 60 years of age and older (28.7%). To investigate age-effects, the sample was divided into five age groups. Individuals 60 years and older were least likely to report olfactory hallucinations (13.2%, *n = 14*). The odds of reporting olfactory hallucinations in the youngest age group was more than four times higher compared to individuals 60 years of age and older (*OR 4.8, 95% CI 2.4-9.2*). The sample contained 54.5% women. Analyses revealed that women reported olfactory hallucinations more often than men (5.7% vs. 2.5%; *OR 2.3, 95% CI 1.5 -3.6*). See Table 2 for prevalence rates of olfactory hallucinations by age group and sex.

The largest proportion of the sample had up to 10 years of education (39.9%), 35.7% had 10-14 years and 24% at least 15 years of education. Comparing levels of education and occurrence of olfactory hallucinations showed that individuals with 11-14 years of education reported olfactory hallucinations significantly more often compared to those with at least 15 years of education (*OR 2.1, 95% CI 1.2 – 3.6*).

The frequency distribution of health-related factors potentially associated with olfactory hallucinations and corresponding prevalence rates are shown in Table 3. Of the sample, 11.4% reported poor/fair mental health, 47.4% reported good and 41.1% excellent health. Of the individuals reporting olfactory hallucinations, 26.9% reported fair/poor mental health compared to 26% indicating excellent and 47% good mental health. The chance of reporting olfactory hallucinations in individuals with fair/poor health was significantly higher than in those individuals reporting excellent health (*OR 4.0, 95% CI 2.3 – 6.9*).

About 8% of individuals reporting symptoms of depression (HADS depression score > 7) and more than 10% of the individuals reporting symptoms of anxiety (HADS anxiety score > 7) reported olfactory hallucinations compared to 3.8% with HADS depression score ≤ 7 and 2.8% with HADS anxiety score ≤ 7 (*OR depression 2.2 (95% CI 1.3 - 3.8)* and *OR anxiety 3.9 (95% CI 2.5 – 5.9)*).

Of the sample, 15.8% (*n = 393*) reported having experienced danger/accident while 32.9% (*n = 829*) reported having experienced bullying/humiliation. The chance of reporting olfactory hallucinations in these groups was significantly higher when reporting the experience of danger/accident (*OR 2.5, 95% CI 1.7 – 3.9*) and when reporting for the experience of bullying/humiliation (*OR 3.7, 95% CI 2.4 – 5.5*) as compared to individuals not having experienced such severe life events.

Approximately 14% of the sample reported having used illicit drugs. Of the individuals experiencing olfactory hallucinations, 27.4% indicated the use of illicit drugs. The chance of reporting olfactory hallucinations in the individuals reporting drug use was significantly higher (*OR 2.4, 95% CI 1.5 – 3.7*) compared to those not having used illicit drugs but experiencing olfactory hallucinations.

Regarding alcohol use, 8.7% of the sample indicated no alcohol use, 69.5% reported a frequency of 1-4 monthly, and 21.8% reported a frequency of two or more times weekly. Of the individuals reporting olfactory hallucinations, the highest percentage indicated alcohol use 1-4 times monthly. The likelihood of olfactory hallucinations decreased with an increased use of alcohol (1-4 times monthly: *OR 0.6, 95% CI 0.3-1.1*) and two or more times weekly (*OR 0.4, 95% CI 0.2-0.8*).

Table 4 shows the results of the multivariate logistic regression analysis. There are main effects of sex and age but no interaction between these factors. Being female increased the likelihood of olfactory hallucinations significantly (*OR 2.3, 95% CI 1.5 – 3.8)*. The model

Table 1

Frequency distribution of demographic characteristics and olfactory hallucinations in a Norwegian population sample and results form separate logistic regression models with Odds Ratio (OR) and corresponding 95% confidence interval (CI).

	Participants no. (%)(n = 2500)*	Olfactory hallucinations reported			Prevalence OH^, %(95% CI)	OR (CI)
		No(n = 2245)	Possibly applies to me(n = 149)	Certainly applies to me(n = 106)		
Age						
below 30 years	322 (12.9)	265 (11.8)	29 (19.5)	28 (26.4)	8.7 (5.9 - 12.3)	4.8 (2.4 - 9.2)
30-39 years	408 (16.3)	359 (16.0)	31 (20.8)	18 (17.0)	4.4 (2.6 - 6.9)	2.3 (1.1 - 4.7)
40-49 years	520 (20.8)	464 (20.7)	29 (19.5)	27 (25.5)	5.2 (3.4 - 7.5)	2.8 (1.4 - 5.3)
50-59 years	533 (21.3)	481 (21.4)	33 (22.1)	19 (17.9)	3.6 (2.2 - 5.5)	1.9 (0.9 - 3.7)
60 and older	717 (28.7)	676 (30.1)	27 (18.1)	14 (13.2)	2.0 (1.1 - 3.3)	1 [Reference]
Sex						
Female	1360 (45.6)	1185 (52.8)	98 (65.8)	77 (72.6)	5.7 (4.5 - 7.0)	2.3 (1.5 - 3.6)
Male	1140 (54.5)	1060 (47.2)	51 (34.2)	29 (27.3)	2.5 (1.7 - 3.6)	1 [Reference]
Education						
up to 10 years	994 (39.9)	894 (40.0)	62 (41.6)	38 (36.2)	3.8 (2.7 - 5.2)	1.4 (0.8 - 2.5)
11-14 years	889 (35.7)	777 (34.7)	62 (41.6)	50 (47.6)	5.6 (4.2 - 7.3)	2.1 (1.2 - 3.6)
15 years and more	607 (24.4)	565 (25.3)	25 (16.8)	17 (16.2)	2.8 (1.6 - 4.4)	1 [Reference]

* might vary depending on missing data

^ Based on category "Certainly applies to me"

Table 2

Prevalence of olfactory hallucinations by age group and sex with 95% Confidence Intervals (95% CI)

	< 30 years	30-39 years	40-49 years	50-59 years	60 + years
Women	9.9 (6.1 - 14.8)	6.1 (3.4 - 10.0)	6.8 (4.2 - 10.4)	4.8 (2.6 - 7.9)	2.6 (1.2 - 4.9)
Men	6.7 (2.9 - 12.8)	2.2 (0.6 - 5.6)	3.1 (1.2 - 6.2)	2.1 (0.7 - 4.8)	1.3 (0.4 - 3.1)

showed further that when both factors sex and age were included in the model, not all categories were significant and significant differences were only found between the oldest and the youngest age group (*OR 3.4, 95% CI 1.7 -6.9*). The increasing *OR* (from 1.4 to 3.4) indicated, however, an age trend. Self-reported anxiety and severe life events remained in the model indicating that there was a higher likelihood of reporting olfactory hallucinations associated with being bullied/humiliated (*OR 2.3, 95% CI 1.5 – 3.6*) and having experienced danger (*OR 2.7, 95% CI 1.7 – 4.4*). None of the other factors from the univariate regression models became significant. Table 4 shows *OR* and *p*-values for the association of olfactory hallucinations with variables from the multivariate regression model.

3.1. Olfactory hallucinations in combination with hallucinations in other modalities

Of the 4.2% participants who reported olfactory hallucinations, 44% (*n = 47*) reported solely olfactory hallucinations. For only one other modality, approximately 1.2% (n = 29) reported having only experienced auditory hallucinations, 1.5% (n = 38) visual hallucinations and 1.1% (n = 28) tactile hallucinations. Forty-two individuals (1.7%) reported hallucinations in two modalities, 1.2% (n = 30) in three and 0.5% (n = 12) in all four modalities. The combinations of hallucinations from all modalities are shown in Table 5. Of the individuals reporting hallucinations in two modalities, 57% reported olfactory hallucinations, of those reporting hallucinations in three modalities, 77% included olfactory hallucinations. Olfactory hallucinations were the most often occurring in combination with tactile hallucinations (75%).

4. Discussion

The present study investigated the prevalence of olfactory hallucinations in a large population-based Norwegian sample, factors associated with these and their occurrence in combination with hallucinations in other sensory modalities. The results revealed a prevalence of 4.2% in the sample, with younger individuals and women reporting olfactory hallucinations most frequently. Olfactory hallucinations were associated with symptoms of anxiety as well as with having experienced severe life-events. Approximately 44% of individuals reported solely olfactory hallucinations while the remaining experienced olfactory hallucinations in combination with hallucinations in other modalities.

The prevalence rate for olfactory hallucinations of 4.2% is lower in this population compared to earlier studies that report 6-6.5% in the large population-based samples (Bainbridge et al., 2018; Rawal et al., 2016). These differences become even larger when we apply the age-range of 40 years as the lower age-limit (3.4%) as was the case in those studies. A possible explanation would be varying assessment formats and response categories. All studies were alike in using a single item question but differed in using interviews (Bainbridge et al., 2018; Rawal et al., 2016) versus a questionnaire (our study). Furthermore, response categories differed between "yes/no" (Bainbridge et al., 2018; Rawal et al., 2016) to five response categories (our study) of which "certainly applies to me" was applied to calculate the above prevalence rate. The prevalence rate in our study would have increased to 10.2% if we had combined the categories "possibly applies to me" and "certainly applies to me". This number would clearly have exceeded earlier reports. Yet, as initially reasoned, the decision on the strictest category seemed most appropriate to address the topic since data derived from a single item addressing (a) rather specific, retrospective experience(s), (b) possibly dating back a long time, and/or (c) not indicating a specific time frame (Bainbridge et al. and Rawal et al. asked about the past 12 months). By applying the strict category, we may have missed participants with a tendency to never answer the most extreme values in a questionnaire and thus the prevalence rate reported here may be underestimated. We therefore followed the advice of a reviewer and re-analyzed the data combining the two answer categories ("possibly applies to me" and certainly applies to me). The results did not change the reported findings (see Supplement).

The significant age and sex differences corroborate and extend earlier findings (Bainbridge et al., 2018; Ohayon, 2000; Rawal et al., 2016). Increasing age is associated with reduced occurrence of olfactory hallucinations (Bainbridge et al., 2018). Although Sjolund and colleagues (2017) did not corroborate an age-related decrease of olfactory hallucinations, this seems to relate to the age-range included in their sample (60-90 years), where differences may not be as large as from younger to older age. In the olfactory literature, an age-related increase in olfactory dysfunction is well-known, in particular for qualitative functions such as identification ability and sensitivity (Doty & Kamath,

Table 3

Prevalence of olfactory hallucinations by health factors in a Norwegian population sample 18 years and older and results from separate logistic regression models with Odds Ratio (OR) and corresponding 95% confidence interval (CI). * might vary depednding on missing data (comment to the editor - I am not able to include this footnote as in Table 1.

	Participants no. (%)(n = 2500)*	OH reported Yes(n = 106)	Prevalence OH, %(95% CI)	OR (CI)
Mental health				
Excellent	1023 (41.1)	27 (26.0)	2.6 (1.7 - 3.8)	1 [Reference]
Good	1184 (47.5)	49 (47.1)	4.1 (3.1 - 5.4)	1.6 (1.0 - 2.6)
Fair/poor	284 (11.4)	28 (26.9)	9.9 (6.7 - 13.9)	4.0 (2.3 - 6.9)
Self-reported				
Depression (HADS sum ≤ 7)	2249 (90.3)	85 (80.2)	3.8 (3.0 - 4.7)	1 [Reference]
Depression (HADS sum > 7)	241 (9.7)	19 (18.3)	7.9 (4.8 - 12.0)	2.2 (1.3 - 3.8)
Anxiety (HADS sum ≤ 7)	2028 (81.5)	57 (54.3)	2.8 (2.1 - 3.6)	1 [Reference]
Anxiety (HADS sum > 7)	461(18.5)	48 (45.7)	10.4 (7.8 - 13.6)	3.9 (2.5 - 5.9)
Severe life events				
No experience of danger/ accident	2096 (84.2)	73 (68.9)	3.5 (2.7 - 4.4)	1 [Reference]
Experience of danger/ accident	393 (15.8)	33 (31.1)	8.4 (5.9 - 11.6)	2.5 (1.7 - 3.9)
No exprerience of bullying/ humiliation	1672 (67.1)	39 (37.1)	2.3 (1.7 - 3.2)	1 [Reference]
Bullying/ humiliation	820 (32.9)	66 (62.9)	8.0 (6.3 - 10.1)	3.7 (2.4 - 5.5)
Use of illicit drugs				
No	2142 (85.7)	77 (72.6)	3.6 (2.8 - 4.5)	1 [Reference]
Yes	358 (14.3)	29 (27.4)	8.1 (5.5 -11.4)	2.4 (1.5 - 3.7)
Alcohole use frequency				
Nondrinker	217 (8.7)	15 (14.3)	6.9 (3.9 - 11.1)	1 [Reference]
1-4 monthly	1729 (69.5)	75 (71.4)	4.3 (3.4 - 5.4)	0.6 (0.3 - 1.1)
2 or more times weekly	543 (21.8)	15 (14.3)	2.8 (1.6 - 4.5)	0.4 (0.2 -0.8)

Table 4

Multivariate regression model and odd ratios with remaining variables for OHs and associated factors in a Norwegian population bases sample

	OR (95% CI)	p	OR (95% CI)
Sex			
Male	1 [Reference]		
Female	2.3 (1.5 -3.8)	< 0.01	
Age			
60 and older	1 [Reference]		1 [Reference]
50-59 years	1.4 (0.7 - 2.8)	0.38	1.83 (0.9 - 3.4)
40-49 years	1.9 (1.0 - 3.8)	0.05	2.45 (1.4 - 4.4)
30-39 years	1.9 (0.9 - 4.0)	0.09	2.77 (1.4 - 5.3)
below 30 years	3.4 (1.7 - 6.9)	< 0.01	3.39 (2.1 - 7.2)
Self-reported			
Anxiety (HADS sum ≤ 7)	1 [Reference]		1 [Reference]
Anxiety (HADS sum > 7)	2.2(1.4 - 3.4)	< 0.01	2.38 (1.5 - 3.7)
Severe life events			
No exprerience of bullying/ humiliation	1 [Reference]		1 [Reference]
Bullying/humiliation	2.3 (1.5 - 3.6)	< 0.01	2.4 (1.5 - 3.7)
No experience of danger/accident	1 [Reference]		1 [Reference]
Experience of danger/accident	2.7 (1.7- 4.4)	< 0.01	2.45 (1.6- 4.0)

Table 5

Occurrence of OHs and in combination with hallucinations in other modalities

Hallucinations in one modality	142 (5.7%)
Olfactory	47 (1.9%)
Auditory	29 (1.2%)
Visual	38 (1.5%)
Tactile	28 (1.1%)
Hallucinations in two modalities	**42 (1.7%)**
Olfactory and tactile	13 (0.5%)
Olfactory and auditory	1 (0.0%)
Olfactory and visual	10 (0.4%)
Auditory and visual	5 (0.2%)
Auditory and tactile	3 (0.1%)
Visual and tactile	10 (0.4%)
Hallucinations in three modalities	**30 (1.2%)**
Olfactory, tactile, and auditory	6 (0.2%)
Olfactory, tactile, and visual	13 (0.5%)
Olfactory, auditory, and visual	4 (0.2%)
Auditory, visual, and tactile	7(0.3%)
Hallucinations in four modalities	**12 (0.5%)**

2014). The decrease in qualitative dysfunction seems to go in the opposite direction. In the somatic literature, including chemosensory samples from ear, nose and throat clinics, olfactory hallucinations are often (but not always) associated with quantitative olfactory loss (Bramerson et al., 2007; Reden et al., 2007). In studies including patients with schizophrenia or individuals from the general population, olfactory hallucinations do not seem to be related to impaired odor identification (Bainbridge et al., 2018; Hudry, Saoud, D'Amato, Dalery, & Royet, 2002; Moberg et al., 1999; Sjolund et al., 2017).

Inconsistent findings may in part originate from different causes for olfactory hallucinations that are not yet completely understood. For example, both peripheral and central causes of olfactory hallucinations have been described (Frasnelli, Landis, et al., 2004; Saltagi, Rabbani, Ting, & Higgins, 2018). Peripheral causes related to dysfunction at the level of olfactory neurons and receptors, in turn leading to inappropriate representations of olfactory stimuli (D. A. Leopold et al., 1991; Saltagi et al., 2018). Peripheral causes, for instance, may be more prevalent in patients with olfactory dysfunction. Central causes refer to damage of the cortical olfactory pathway and structures such as the amygdala and orbitofrontal areas (Bowman, Kording, & Gottfried, 2012; Fjaeldstad et al., 2017; Lotsch & Hummel, 2019). These may be more likely to be found in healthy individuals. In population-based samples like in the present study, the origins of olfactory hallucinations have remained elusive and may have different underlying causes.

Previous studies have demonstrated that females perform better than males on quantitative olfactory tasks and that younger individuals outperform older (Doty & Kamath, 2014). Our findings show that females and younger individuals report olfactory hallucinations more often than males and older individuals, respectively. This seems to support the suggestion that sensitivity for odors may contribute to a higher predisposition for olfactory hallucinations (Sjolund et al., 2017). In that smell experiences can be more elusive than other sensory experiences, particularly vague perceptions may be more vulnerable to misinterpretations.

The finding that olfactory hallucinations most often occur in individuals below the age of 30 years is new and thus a novel contribution. There is still scarce data on olfactory hallucinations in younger adults from the general population. Ohayon's (2000) study included individuals from age 15 years but did not differentiate between age-groups. The age effect should be replicated, and its implications should be investigated in future studies. There is some indication that

olfactory hallucinations are associated with an earlier onset of psychotic illness in psychosis-prone individuals (Kwapil et al., 1996). Yet, developmental studies investigating hallucinations in younger individuals in other modalities, in particular auditory and visual modalities, have shown that these can be transient phenomena during healthy development (Jardri et al., 2014; Maijer et al., 2019). Linscott and van Os (2013) concluded that psychotic experiences (including hallucinations) are transient and remitted in 80% in the general population, while 7% may develop a psychotic disorder. They reported further that stressful and traumatic events were significantly associated with psychotic experiences. This is for the first time supported in our findings by showing that anxiety and stressful life-events remained significant predictors of olfactory hallucinations in the multivariate model. Anxiety has been shown to have predictive value for auditory verbal hallucination predisposition in non-clinical individuals (Allen et al., 2005) and has been shown to have predictive value for the triggering and maintenance of hallucinations in clinical populations (Freeman & Garety, 2003). Additionally, the experience of trauma/stressful life events can contribute to heightened anxiety (Freeman & Fowler, 2009). So far, findings indicate that anxiety may modulate basic olfactory perception in that normal individuals with high anxiety levels demonstrate an attentional bias and hypersensitivity in olfactory perception. They detect and process odors faster compared to individuals with low anxiety levels (Krusemark & Li, 2012; La Buissonniere-Ariza, Lepore, Kojok, & Frasnelli, 2013). Nevertheless, the findings suggest that these individuals who experience olfactory hallucinations may have less functioning and may even be more apt to develop psychopathology.

However, there is still a gap that needs to be investigated between olfactory hallucinations and hypersensitivity since there is no clear indication that odor detection sensitivity is impaired in psychiatric patients despite the presence of olfactory hallucinations. It may therefore be important to include cognitive processes such as reasoning and memory to deepen our understanding of potential processes that underlie olfactory hallucinations.

Our data do not allow any conclusion concerning the direction of the reported associations, although it seems plausible to assume that olfactory hallucinations and anxiety may occur *after* a severe/stressful event. Odor memory is known to be long-lasting and significantly associated with autobiographical experiences (Engen, 1973; Sullivan, Landers, Yeaman, & Wilson, 2000; Willander & Larsson, 2006). Odors are in particular maintained in autobiographical memory when contents are important or emotionally charged. Individuals with post-traumatic stress disorder (PTSD) report that trauma-related odors are strong reminders of past events and are related to olfactory hallucinations (Cortese, Leslie, & Uhde, 2015; Vermetten & Bremner, 2003). Additionally, autobiographical connotations in olfactory hallucinations have been reported in schizophrenic patients (Stevenson et al., 2011) and normal elderly individuals (Sjolund et al., 2017). Yet, one must keep in mind that being bullying/humiliated or other stressful life events, as reported by individuals in our sample, may not match the emotionally charged experiences of war veterans. Secondly, models which state that auditory and visual hallucinations may arise from misattributions of visual and auditory imagery or from involuntary memories are somewhat less relevant for olfactory hallucinations in that olfactory images are hard to generate (Crowder & Schab, 1995; Engen, 1991; Stevenson & Case, 2005). Explicit analyses of the association between olfactory hallucinations and odor imaging ability in schizophrenic patients showed that one-third reported that olfactory hallucinations reminded them of an odor experience in the past (Stevenson et al., 2011). Yet, Stevenson and colleagues (2011) could not confirm a relationship between olfactory hallucinations and odor imagery ability, and they failed to observe contextual triggers for olfactory hallucinations. Our data do not provide information on whether the content of the olfactory hallucinations was related to autobiographical memories and stressful life-events.

More than half of the individuals reporting olfactory hallucinations indicated that they experienced hallucinations in other modalities as

well. This finding is not new and previous findings have shown significant correlations between hallucinations in different modalities within the same individual (Laroi & van der Linden, 2005; Preti et al., 2014). It has been suggested that there may be a general factor increasing the proneness to hallucinations and that hallucinations in individual modalities may be sufficient to lead to individual sensory contributions and symptom differences (Mitchell et al., 2017). Our data supports this multidimensionality and the need for more detailed assessment of individuals hallucinations which is critical to further understand these phenomena. The association between olfactory hallucinations and in particular tactile hallucinations has also been emphasized in patient studies (Lewandowski et al., 2009; Mueser, Bellack, & Brady, 1990; Stevenson et al., 2011). A recurring suggestion for this observation is that sniffing is a tactile experience that is used to adjust perceived odor intensity (Frasnelli, Heilmann, & Hummel, 2004; Teghtsoonian, Teghtsoonian, Berglund, & Berglund, 1978). Sniffing induces neural activity in olfactory processing areas of the brain (Sobel et al., 1998), even if no odor is present. Stevenson et al. (2011) suggest that individuals experiencing tactile and olfactory hallucinations "*experience sensations of sniffing in the absence of genuine sniffing (i.e., hallucinatory sniffs), leading to olfactory cortical activation and an olfactory hallucination*" (Stevenson et al., 2001; page 326). This may also apply to our participants.

The present study has several limitations. Only 32% of the approached individuals responded to the invitation to participate in the general study. This despite the fact that a reminder was sent to all the 8,000 individuals 6 weeks after the initial invitation (for more detail regarding this, see Kråkvik et al., 2015). Thus, it was not possible to carry out analyses on these individuals as they did not wish to participate in the study and therefore no data exists for them. We can only speculate about the relatively low participation rate and the consequences for the representativeness of the sample of those who actually participated. It is possible that individuals who were more prone to hallucinations were also more likely to participate than those who were less likely to have experienced hallucinations before. This could have led to higher endorsement rates and a larger proportion of individuals reporting olfactory hallucinations in particular and hallucinations in general. Secondly, we relied on self-reported information on psychiatric or somatic symptoms from the participants, which may have impacted our results. Self-reported status of olfactory function has been shown to be somewhat unreliable and biased. We argue that there are no other ways to assess qualitative olfactory function and that we addressed this issue by applying the strictest category for olfactory hallucinations in our analyses. Likewise, we only included results from self-reported symptoms of anxiety, which is not a clinical diagnosis. However, our results contribute to the existing literature by showing that olfactory hallucinations are associated with emotional symptoms triggering distress and potentially reducing quality of life. They highlight that olfactory function should be taken into account and that these symptoms should be taken more seriously. Future studies on olfactory hallucinations should encompass detailed and comprehensive assessments that include dimensions such as specific time frames, frequency, duration, quality, and intensity (Table 6).

Furthermore, quantitative assessment and possible autobiographic memories and the individuals' reasoning around these experiences in addition to medical, social and biological factors need to be included in future studies. Another important aspect would be to assess the implication and impact of these experiences on daily life (e.g., distressing, unnoticed).

5. Conclusion

In sum, our findings add to the existing literature by showing that olfactory hallucinations occur more in young individuals and are associated with stressful life events and anxiety. The underlying reasons are unknown but several explanations are feasible. It is likely that individuals with olfactory hallucinations in our study constitute a

Table 6
Suggested dimensions for the assessment of olfactory hallucinations

Dimension	Potential response categories
Duration (across lifetime)	Less than one year, 1-3 years, 4-5 years, 6 and more years
Latest occurrence	Present now, during the past week, during the past month, 2-6 months ago, > 6 months ago
Frequency	Monthly, weekly, daily,
Duration (single episode)	Fleeting/transient, a few minutes, a few hours, most of the day
Intensity	Faint, medium, strong
Preceding events	Diseases (e.g., upper respiratory tract infection, head trauma, neurodegenerative disease, chronic rhinosinusitis, migraine, others)
Character of phantom smell	Smoky/burnt, perfume, mold, rotten, flower, other
Autobiographical connotations	Yes/no

heterogeneous group. Nevertheless, regardless of the specific underlying reasons for olfactory hallucinations in individuals, there seems to be enough evidence that olfactory hallucinations should be taken seriously and, when present, should be further investigated, given the increasing recognition that olfactory function is an important factor for well-being and quality of life.

Author statement

Contribution to the manuscript
Writing manuscript: Wehling, Bless, Hirnstein, Kråkvik, Vedul-Kjelsås, Hugdahl, Kalhovde, Larøi
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Data collection: Kråkvik, Vedul- Kjelsås
Study design: Kråkvik

Declaration of Competing Interest

All authors declare that there are no financial or other relationships that might lead to a conflict of interest.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.psychres.2021.114117.

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