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Olfactory Impairment and Close Social Relationships. A Narrative Review

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Abstract

Olfactory impairment is one of the more unique symptoms of COVID-19 infection and has therefore enjoyed increased public attention in recent months. Olfactory impairment has various implications and consequences ranging from difficulty detecting dangerous pathogens to hindering social functioning and social behaviors. We provide an overview of how olfactory impairment can impact 3 types of close social relationships: family relationships, friendships, and romantic relationships. Evidence is divided into several categories representing potential mechanisms by which olfactory impairment can impact close social relationships: bonding disruptions, decreased social support, missed group-eating experiences, hygiene concerns, and altered sexual behaviors. We conclude with a discussion of emerging future research questions.

Key words: family, friends, olfactory impairment, olfactory loss, romantic, social relationships

Introduction

From the mouthwatering aroma of freshly baked brownies to the earthly scent of dirt after a spring shower, our sense of smell provides us with a myriad of information about the world around us. Olfactory impairment is often overlooked, perhaps because (unlike blindness or deafness) it is not immediately apparent in others. However, olfactory loss affects a relatively large portion of the general population, with studies indicating that around 15–20% of the population exhibits some level of olfactory sensory deprivation and 2.5–5% display complete olfactory loss (Brämerson et al. 2004; Landis et al. 2004; Schubert et al. 2012). And while there are readily available tools to enhance impairments of other senses, such as eyeglasses and hearing aids, no comparable device exists to enhance an impaired sense of smell. Thus, research aimed at learning about and compensating for deficits due to olfactory impairment could benefit a large portion of the population and warrants increased scholarly attention.

Different types of olfactory impairments

There are multiple ways to test olfactory abilities. Examples of such objective tests are Sniffin' sticks test (SST; Hummel et al. 1997a) and University of Pennsylvania Smell Identification Test (UPSIT, Doty et al. 1984a) which both measure the participant's ability to 1) discriminate, 2) identify, and 3) detect odors. These psychophysical tests illustrate the range of different olfactory abilities that can be measured as well as types of olfactory impairments (for a review, see Su et al. 2021). For example, although quite rare, an individual can have an increased ability to detect odors, a condition called hyperosmia (Hummel et al. 2017c). The most known term for olfactory impairment is anosmia that describes the total loss of olfactory functioning, while hyposmia (or microsmia) are defined as reduced olfactory functioning (Hummel et al. 2017c). Olfactory dysfunctions can either be present from birth (congenital) or acquired, and an acquired dysfunction can be either temporary or permanent. Several other types of olfactory dysfunctions have been identified, for example specific anosmia is a condition in which a person can smell most odors normally but has difficulty smelling one specific odor

Table 1. Different close social relationships and their links to olfactory impairment with research examples

	Implications of olfactory impairment	Research examples
Family relationships	Bonding and attachment	Mothers ability to identify their infant's odor and bonding difficulties are linked (Croy et al. 2019)
	Social support	Infants smelling their mother's scent show reduced pain reactions and lower heart rates in response to a stressor (Akcan and Polat 2016)
Friendship relationships	Eating behaviors	Anosmics report that they avoid eating with others (Croy et al. 2012)
	Hygiene concerns	Anosmics report more concern about how others perceive their body odors (Blomqvist et al. 2004)
	Social functioning/support	Persons with worse olfactory function were more likely to report loneliness (Desiato et al. 2020)
Romantic relationships	Eating behaviors	Anosmic individuals report asking their spouse or family member to taste foods they believe to be spoiled (Nordin et al, 2011)
	Sexual behaviors	Anosmic men have less sexual partners and anosmic women experience decreased partnership security (Croy et al. 2013)
	Social functioning/support	The body odor of a partner has the capacity to alter stress levels (Hofer et al. 2018)

(for a complete list of olfactory dysfunctions, including qualitative dysfunctions, see Hummel et al. 2017c). However, for the purposes of this review we will combine all olfactory dysfunctions into one group, and focus on examining how these conditions impact close social relationships.

There are a variety of potential causes of olfactory impairment. Some possible recognized causes are sinonasal disorders or injuries to the head. These circumstances can lead to decreases in olfactory functioning either by damaging the olfactory nerve and/or central structures involved in olfactory processing or by direct injury to the nasal pathway that allows odorants to reach the olfactory receptor (Hummel et al. 2017b). A respiratory tract infection can also temporarily obstruct the nasal airway and cause olfactory impairment (URTI) (Hummel et al. 2017b), a common side effect of the common cold. Finally, as with other senses, olfactory ability generally decreases with age (Doty et al. 1984b; Schubert et al. 2012).

Recently anosmia and hyposmia have become familiar terms due to COVID-19, because olfactory sensory loss is one of the more unique symptoms and is being monitored as an early warning sign to COVID-19 infection (Giacomelli et al. 2020). Early data show that between 60% and 90% of COVID-19 patients report partial or total smell loss (Chiesa-Estomba et al. 2020; Lechien et al. 2020). Smell loss is often the only symptom of mild cases of COVID-19 infection, and frequently lingers long after all other symptoms have dissipated (Lechien et al., 2021). One recent study found that while most people recover their sense of smell with time—the average recovery time was about 22 days—15% of patients had still not regained their olfactory ability after 2 months and 5% had not regained it after 6 months (Lechien et al. 2021). Thus, considerable uncertainty and anxiety exists for patients suffering from COVID-19 related olfactory loss concerning when and whether they will regain their sense of smell—as evidenced by the fact that a new Facebook group "Covid-19 Smell and Taste Loss," created in March 2020, has already gained 27 000+ members.

At the same time, the COVID-19 pandemic is causing restrictions in people's ability to gather and interact socially. We suggest that if there was ever a time to reflect upon the importance of olfaction within social relationships, now is the time. Pellegrino et al. (2020) have suggested how and where future studies are necessary to gain a better understanding of the connection between COVID-19 and olfactory impairments. We add to their call that not only do we need to understand the physiological, chemical and neurological consequences of COVID-19 and olfactory impairments, we also need to examine the social consequences.

Impacts of olfactory impairments

So just how does olfactory impairment impact an individual? One straightforward consequence is a reduced ability to detect scent-based danger cues. Many sources of danger are detected via scent, including detecting certain toxic chemicals, gas leaks, smoke, and burning. Indeed, one study showed that compared to age matched controls, congenital anosmics report significantly more household accidents (Croy et al. 2012). Our sense of smell can also help us avoid dangerous pathogens; for example, the disgusting scent of spoiled food and rotting substances discourages us from being in close contact with these potentially harmful substances. Other humans also represent a possible pathogen risk, and accordingly, when we encounter others with scent cues denoting sickness this promotes interpersonal avoidance of these potentially infectious individuals (Sarolidou et al. 2020). People with olfactory impairment may miss these scent-based cues denoting risks such as smoke or sickness in others and thus be exposed to more sources of danger. This may partially explain the well-established association between olfactory loss and mortality in older adults (Pinto et al. 2014; Van Regemorter et al. 2020).

In addition to its direct influence on risk avoidance, olfactory dysfunction can also have indirect effects. When compared to controls, congenital anosmics reported significantly higher rates of depression, increased social insecurity, and altered sexual trajectories (Croy et al. 2012, 2013). Also, after losing their sense of smell, patients report problems in social and family life (Brämerson et al. 2007) and complain of an overall decrease in their general quality of life (Merkonidis et al. 2015). These findings indicate that impairments to the sense of smell may have a complicated relationship with social functioning and mental health. It is this relation that we set out to explore in this review.

Scents have an important role within subtle social communication and can improve socially perceptiveness. Body odor may convey a variety of personality traits, such as dominance and neuroticism (Sorokowska et al. 2016), and a variety of emotions including happiness and disgust (Chen and Haviland-Jones, 2000; de Groot et al. 2015; Zheng et al. 2018). A sizable body of work examines the olfactory communication of fear; a meta-analysis from by de Groot and Smeets (2017) combines results from 26 articles examining the communication of fear, anxiety or stress via body odor and found that reactions to a control scent and a fear scent differ on average by one third of a standard deviation (a Hedges' *g* of 0.36), suggesting that humans can detect the scent of another person's fear. Thus, one potential effect of olfactory impairment could be missing out on the subtle communication of emotions that takes place within a conversation. This may cause individuals with olfactory impairment to have more trouble understanding, empathizing and connecting with others. Indeed, this could be part of the reason why decreased olfactory ability has been correlated with reduced social network size (Zou et al. 2016).

Social relationships

Social relationships come in many forms, and 3 of the primary relationships in human life are those between family members, friends, and romantic partners. These types of relationships are important in different ways, for example having children is associated with increased meaning in life (Nelson et al. 2013), longer friendships have been associated with increased life satisfaction (Marion et al. 2013), and satisfying romantic relationships are related to increased physical health (Robles et al. 2014). These relationships also differ in how they are established: friendships and romantic partners are established by choice, while family members are not. Relationships established by choice, such as friendships, are generally reciprocal with both sides contributing resources (e.g., time, energy, support). In contrast, family relationships, such as parental relationships, can be asymmetrical with resources flowing almost exclusively in one direction (e.g., from the parents to children). Differences in how relationships are formed may have implications for the role of olfaction within the bonds, and these differences are highlighted throughout our review.

Current review

As a scientific field, olfaction is remarkable; it brings together chemistry, philosophy, physiology, neuroscience, and psychology. Consequently,

reviews on olfactory functioning have been written with many different goals. Relevant reviews exist summarizing functions of the human olfactory system (Stevenson 2010; Hofer et al. 2020), following olfaction across development (Schaal et al. 2020), reviewing causes and consequences of olfactory dysfunction (Schäfer et al. 2021), examining social olfactory communication of emotion (Lübke and Pause 2015; de Groot et al. 2017), and exploring the role of scent in romantic relationships (Mahmut and Croy 2019). As social psychologists, we also want to contribute with a narrative review with the aim to investigate *how olfactory impairment may impact close social relationships*.

The research articles included in this review were found by searching the keywords "social relationships," "relationships," "olfaction," "friendships," "romantic," "family," "smell disorders," "olfactory impairment," and "anosmia" in various combinations using the search engines Web of Science and Google Scholar. We are dividing close social relationships into 3 groups; family, friendship and romantic (see Table 1). We first highlight 2 ways in which olfactory impairment can negatively impact family relationships; by bonding and attachment disruptions and reduced social support. In the next 2 sections we discuss findings related to friendship and romantic relationships, and focus our attention on the negative impact of olfactory impairment on group eating, perception of social support and functioning, hygiene concerns, and sexual behaviors. We close with a discussion of emerging future directions which may help guide future work to further explore the impact of olfactory impairment on close social relationships.

Family relationships

Bonding and attachment

Family members recognize one another through scent (Porter et al. 1986; Lundström and Jones-Gotman 2009; Lundström et al. 2009). This recognition happens quite rapidly; in fact, mothers who had spent only 10–60 min with their newborns were already able to accurately identify their child's odor 90% of the time (Kaitz et al. 1987). Mothers also find their children's scents pleasant, and prefer them to the scent of an unfamiliar child (Schäfer et al. 2020a).

While most mothers have a clear preference of their own infants' scent, the same is not true of mothers who report difficulty bonding with their baby. One study found that, unlike controls, mothers with bonding difficulties could not identify their own infant's odor at levels above chance (Croy et al. 2019). The mothers with bonding difficulties had significantly lower self-reported olfactory associative ability as well as descriptively—but not significantly—lower objective olfactory abilities. In addition, a mother's self-reported bonding difficulties were negatively correlated with her preference for her child's odor (Croy et al. 2019), indicating that the more difficulty a mother has bonding with her child, the less likely she is to be attracted to her child's odor. The directionality of this effect is currently unclear. Odor preferences for a child may merely be a bi-product of repeated exposure via positive bonding experiences; however, these results could also indicate a "vicious cycle," whereby mothers with an olfactory impairment do not readily perceive their infant's appealing scent cues leading her to approach her infant less and thereby reducing her opportunity to bond and form positive associations with her infant's scent. If future research supports this possibility, olfactory impairment could become a useful risk factor allowing us to identify those at high risk for bonding related difficulties or maternal depression.

In comparison to our other senses, our sense of smell is remarkably mature at birth. Visual information detected by infants is poor and many functions such as scanning ability, depth perception, and contrast sensitivity are quite limited in the first months of human life (Slater 2002). On the other hand, within days an infant will preferentially turn their head towards their mother's scents and react positively to these scents (Makin and Porter 1989; Rattaz et al. 2005; Doucet et al. 2007; Nishitani et al. 2009). Thus, scent-based communication may be especially important for newborns in order to detect the presence of their parents. Infants direct attachment behaviors towards their parents or caretakers (e.g., smile, cry) in order to encourage them to provide the care they need to survive and thrive (Engle and Lhotska 1999). Infants with an olfactory impairment could have more trouble attracting their caretakers which may have especially hazardous consequences during the first months of life. Unfortunately, because olfactory testing is not a standard component of health check ups, anosmia is usually not detected until puberty (Hummel et al. 2017c). This has made studying the developmental consequences of anosmia challenging and left research questions concerning the effects of olfactory dysfunction in infants unanswered.

The sense of smell also has obvious implications for locating food. Indeed, if a baby is placed on its mother's stomach, they will move towards her chest, a behavior which is disrupted if the mother has washed their chest and therefore masked the breast odor (Varendi et al. 2001). Similarly, if a plastic film is placed over the breast (versus not), newborns held near the chest display less interest, mouthing responses, and visual attention (Doucet et al. 2007). Since anosmic infants cannot smell their mothers´ milk, they may face difficulties locating their next meal. In other mammals, olfactory cues are known to be critical for an infant's survival; for example, young rabbits without the ability to smell cannot locate their mother's nipple and will starve to death if they are not hand fed (Schaal et al. 2009). While the situation is less dire for human babies, an inability to smell could reduce mouthing and other appetitive cues that would normally indicate hunger creating barriers for effective communication within the mother infant dyad.

Social support

Exposure to the scent of a caregiver has positive downstream consequences for mental health. For example, during a briefly painful event (a routine heel stick), infants smelling their mother's scent displayed reduced stress reactions, including reduced pain reactions, lower heart rates, and lower cortisol responses (e.g., Badiee et al. 2013; Akcan and Polat 2016; see Schaal et al. 2020 for a review). In one study, 7-month-old infants who smelled their mother's scent while viewing happy versus fearful faces did not display the typical fear brain response to the fearful faces, whereas the fear brain response appeared as expected in control contexts (other mother's odor or no odor; Jessen 2020). Overall, the evidence clearly indicates that maternal scents buffer stress for infants, which could have a variety of consequences such as improved regulation of emotions and reduced anxiety and fear of novel situations. Since these benefits are not available to anosmic infants, they may have more trouble regulating their negative emotions and experience higher levels of chronic stress. This indicates that testing newborns for olfactory abilities (in addition to vision and hearing) would be useful so that extra parental support (e.g., faster intervening during stressful events) could be provided to offset the loss of olfactory stress buffering.

The evidence for stress buffering within other familial relationships, such as the parent to child bond, is less clear. One study found that smelling odors from infants activated neurological reward regions in women's brains (Lundström et al. 2013). It is possible that

familial scent exposure (e.g., parent to child, between siblings) is broadly comforting and stress reducing in the same way that maternal scents are comforting for infants, however empirical research testing this idea is not available. Scent based stress buffering could have a number of consequences for mental health such as improved sleep, reduced anxiety, and reduced depression, and warrants future empirical consideration. This is especially true considering that, pandemic related lockdowns aside, physical separation from social support networks is common. For example, in 2016 alone, U.S. residents embarked on more than 2 billion trips (U.S. Travel Association, 2016). During these separation periods, scent based social support could be especially valuable.

Summary

The available evidence indicates that family members are able to identify one another via scent, and that identification of these scents may have positive consequences for bonding and mental health of the perceiver.

In this section we focused on the potential impact of olfactory loss within a cohabiting family unit (parents and their children). We did not consider other family structures, such as relationships between parents and their older children. Differences may be expected as family members move through developmental stages; for example, mothers' ratings of their child's body odors decrease as their child ages (Croy et al. 2017). Since older children and adults' body odors are less appealing than babies, one unexplored possibility is that olfactory dysfunction may hold certain benefits for social interactions between older family members. Indeed, one study found that 7% of children surveyed would prefer not to be able to perceive their family members' odors (Ferdenzi et al. 2008). For instance, if specific odors are unappealing (e.g., bad breath or increasingly smelly older children), reduced olfactory function might ease interactions with these unpleasant smelling individuals. A curvilinear relationship could also be envisioned, in which a moderate sensitivity to scents is useful for social functioning but a heightened sensitivity can lead to avoidance of certain interpersonal interactions. Due to the scant evidence examining the role of olfaction within adult relationships, these possibilities remain areas for future research.

This section was also not able to address relationships with extended family members (e.g., nieces, cousins). The element of cohabitation within a family unit makes regular interaction and communication a necessity, whereas more extended family relationships offer more choice about whether and when to interact. Because of this, noncohabitating family relationships may share more similarities with friendship relationships, described below.

Friendship relationships

Eating behaviors

Smells play a part in both anticipation and stimulation of appetite (Boesveldt and de Graaf, 2017). In fact, in a large survey in the UK with 496 adult participants suffering from an olfactory disorder, over 90% reported that they experienced a reduced appreciation of food and drink and 55% reported they went to restaurants less often than they used to (Philpott and Boak 2014). A similar finding occurred in a Swedish adult sample who reported a reduced interest in food (Blomqvist et al. 2004). In addition, when compared to controls, individuals with anosmia in a German study were more likely to avoid eating with others, which may partially be due to a reduced interest in food and/or their reported increase in social concerns (Croy et al. 2012). Also, because anosmic individuals report higher rates of accidentally eating spoiled foods (Croy et al. 2012), they may also avoid novel eating situations as they need to be more careful about where and what they eat. In a qualitative study with adult British participants who had self-reported olfactory impairments, loss of interest in cooking and embarrassment to serve dishes to friends were among the top consequences reported related to their impairment (Erskine and Philpott 2020). Whatever the reasons, by avoiding shared meals, anosmic individuals miss out on important bonding opportunities with friends as well as opportunities to form new friendships.

Hygiene concerns

People with anosmia worry about their own body odor more often than others (Croy et al. 2012). For example, in a Swedish study, an adult patient group with olfactory impairments were asked about the most negative consequence of their impairments, the most frequent response concerned the lack of awareness about personal hygiene (Blomqvist et al. 2004). This concern about smelling bad is not unrelated to reality. In western societies, people bath often and typically have little discernible body odor. This hygiene focus is argued to be the result of a moralization of cleanliness in western society (Soo and Stevenson 2007). Thus, these concerns about not being able to detect one's own foul body odor can possibly lead to withdrawal from participating in social engagements with friends and/or new acquaintances which would have a negative effect on friendship formation and maintenance.

Social functioning/support

In one German study, anosmic individuals reported much higher levels of social insecurity (at rates twice as high as healthy controls; Croy et al. 2012). This social insecurity may be due in part to hygiene concerns, and perhaps in part to more nuanced factors such as an inability to detect the subtle social cues humans communicate via odor. People use body odor to recognize and learn information about their friends such as their health to their emotional state (Mallet and Schaal 1998; Olsson et al. 2006; Lundström et al. 2008; 2009; Hofer et al. 2020). Not having access to this information about the reactions of their social partner could cause anosmic individuals to be less effective and less confident in social interactions. These social disruptions could have negative consequences for establishing or maintaining a healthy social life. In a large American adult sample olfactory function correlated positively with a fuller social life (number of friends, feeling of closeness to family members, and frequency of socializing; Boesveldt et al., 2017b). Similarly, in a community-based American adult sample, Desiato et al. (2021) found that participants with worse olfactory function were more likely to report being lonely.

Just as social life and loneliness are related to olfaction, so too is depression. Depression is characterized by a depressive mood or loss of pleasure accompanied by cognitive, behavioral, or neurovegetative symptoms that significantly affect the individual's ability to function (WHO, 2010). Many studies indicate a link between olfactory impairment and depression (for a review, see Croy and Hummel 2017). In fact, a recent study shows that the onset of olfactory impairment predicts the development of depression in an older American adult sample (Eliyan et al. 2021). It is possible that olfactory impairment leads to enhanced social difficulties which, in turn, lead to increased depression. For example, one German paper examining adult patients with congenital anosmia found that the magnitude of social worries correlated positively with depression (Croy et al. 2013). It is

also possible that the link between depression and olfactory impairment is driven by a third variable causing both conditions. A final possibility is that a reduction of olfactory input causes changes in the emotional regions of the brain (e.g., reductions in olfactory bulb volume; Negoias et al. 2010), leading to depression. The variety of possibilities described here highlights the need for further investigation on the nature of the relationship between depression and olfactory impairment, and closer exploration of the possibility that close social relationships partially mediate this relationship.

Summary of friendship relationships

To the best of our knowledge, there are few studies directly investigating the role of olfaction in friendships. The studies discussed here indicate links between olfactory impairment and solitary eating behavior, hygiene concerns, and social functioning. The shared implications of these differences are increased constraints on opportunities for forming new friendships and bonding within existing friendships. However, the indirect effects are tricky to disentangle, and more research is needed to fully explore the links between olfactory function and friendship relationships. It is also important to note that most available evidence was conducted on adults, thus leaving a research gap for investigations on younger adults and adolescents, for whom the formation and maintenance of friendships is arguably an even more important factor.

Romantic relationships

Eating behaviors

Before a person enters into a romantic relationship, they must first meet and become close to a potential romantic partner. Since anosmic individuals often avoid social eating events (Croy et al. 2012), this may create obstacles for romantic relationship formation (e.g., reduced interest in dating activities which often include sharing food). However, after a romantic relationship is formed, a partner can become a trusted resource for anosmic individuals, helping them identify scent-based information. For example, in a Swedish adult sample of patients with anosmia or hypnosmia, over half reported that they asked their spouse or other family members to taste food that they suspected to be spoiled (Nordin et al. 2011). Providing practical assistance and emotional support could in general increase the bond within a relationship (Ko and Lewis 2011; Girme et al. 2015), thus perhaps this simple form of assistance could be a positive experience for some couples.

Sexual behavior

The sense of smell requires physical proximity, and there are few things in life involving closer proximity than the act of sex. Thus, it is not surprising that aspects of our sexuality are linked to scent. Early exposure to an individual seems to inhibit sexual interest in that person later in life (known as the Westermarck effect; Schneider and Hendrix 2000). Unrelated children who are raised together are unlikely to marry or have sex once they mature (Shepher 1983). This aversion towards sexual relationships between people who were raised together may be an evolutionary mechanism designed to reduce the chance of inbreeding, and one factor that has been hypothesized to drive this aversion is olfactory cues (Stevenson 2010). Humans have a clear capacity to learn the odor signature of others in their environment (Mallet and Schaal. 1998; Weisfeld et al. 2003; Olsson et al. 2006; Schaal et al. 2020), and acquiring memories of body odors during developmental years may lead to sexual inhibition in response to these odors. Evidence for this hypothesis is limited, however some support exists: one study reported a mutual aversion of body odors between fathers and pubertal daughters (Weisfeld et al. 2003). A second study observed reduced maternal liking for her pubertal sons' odor, compared to ratings of unfamiliar similarly aged boys (Schäfer et al. 2020b). This line of reasoning leads to the interesting and untested possibility that these evolutionary aversions to inbreeding or mating with childhood housemates may be reduced in anosmic individuals.

An impaired sense of smell may play a role in mating strategies and initiation of romantic relationships in a variety of ways. First, it may change who we find attractive. Among a group of female undergraduates in the United States, body odors were ranked as one of the most important contributors for attraction (Herz and Inzlicht 2002), and anosmic individuals would not weigh this information in their assessments of attractiveness. Second, it may change sexual desire. A German study compared adults with olfactory loss and healthy controls and revealed that 29% in the olfactory loss group experienced decreased sexual desire after the onset of olfactory loss (Schäfer et al. 2019). Interestingly this decrease in sexual desire was related to the severity of the olfactory impairment and degree of depression, but not to partnership attachment (Schäfer et al. 2019). An earlier German study observed an even more severe effect, with over half of their adult participant group reporting changes in their sexual behaviour after the onset of their olfactory disorder (Merkonidis et al. 2015). Another German study noted gender differences; anosmic men reported fewer sexual partners compared to control men, while anosmic women felt less secure in their relationships (Croy et al. 2013). In both men and women, these effects are thought to be linked to increased social insecurity—affecting men's confidence to explore new sexual encounters and women's confidence in their long-term romantic partnerships (Croy et al. 2013). A final study found that olfactory sensitivity is positively related to the perceived pleasantness of sexual activities in a younger healthy German sample (Bendas et al. 2018). Overall, this evidence indicates that olfactory dysfunction is linked to decreased interest, enjoyment, and participation in sexual activities.

In addition to changes in our own sexual preferences, our sense of smell may influence what we know about the sexuality of others. For example, younger heterosexual men were able to detect female sexual arousal via scent; when they were exposed to the scent of a sexually aroused woman (versus the scent of a nonaroused woman) and consequently their behaviour and perception changed (Wisman and Shira 2020). In another study, women appeared to be able to detect a man's relationship status via scent; when a group of younger heterosexual women in Australia were exposed to men's body odors they rated odors from single and partnered men differently (Mahmut and Stevenson 2019). In a third study, younger women who rated themselves as very passionately in love their with their current partner, were less likely to be able to identify the scent of an opposite sex friend, which may indicate low attunement to cues from other potential mating partners (Lundström and Jones-Gotman 2009). Thus, the available evidence indicates that olfactory impairment may impact an individual's perception of their potential sexual partners as well as their own interest in sex.

Social functioning/support

Social support is extremely important for health. Meta-analyses suggest that social support is as important for health as a healthy lifestyle or not smoking (Holt-Lunstad et al. 2010; 2015). A romantic partner is a main source of social support for most adults (Coyne

and DeLongis 1986), and even their scent can be comforting (Shoup et al. 2008). In fact, research on healthy younger adults in Canada, Sweden, and USA indicates that exposure to a romantic partner's odor leads to reduced perceptions of stress in reaction to a stressful event (McBurney et al. 2006; Hofer et al. 2018; Granqvist et al. 2019). Perhaps due to the calming quality of a partner's scent, exposure to their body odor also improves sleep among normosmic individuals (Hofer and Chen 2020). The body odor of a romantic partner can be expected to linger within shared spaces such as the bed or living areas in a home. Thus, people with a normally functioning sense of smell regularly have the benefit of this scent exposure, while individuals with olfactory impairment do not. It is also possible that the reduced partnership security among anosmic women discussed earlier (Croy et al. 2012) may, in part, be due to the fact that these women do not receive the consistent reassurance others experience from exposure to their partner's odor. Overall, this reasoning implies that individuals suffering from olfactory impairment (compared to those with normal olfactory abilities) may not get as many benefits from membership in a long-term romantic relationship and this may have consequences for their relationship quality and their physical and mental health.

Summary of romantic relationships

In this section, we summarized findings on romantic relationships and the impact of olfactory impairments. While lack of engagement in social eating events may have negative effects on romantic relationship formation, anosmic individuals in romantic partnerships may gain access to some scent-based information through their partner such as assistance avoiding spoiled foods. In addition, olfactory dysfunction is expected to have a detrimental effect on sexual functioning and stress buffering. In their recent review, Mahmut and Croy (2019) state that they find no studies that have directly examined the impact of olfactory impairments on the initiation or maintenance of relationships. Thus, future research will need to investigate these possibilities further to form a complete picture of how olfactory impairment could impact romantic relationships. In regards to intimate sexual moments, many of the studies conducted have focused on younger Western samples without any olfactory impairments, highlighting the need to expand research activities to a wider range of populations (Roberts et al. 2020).

Discussion

Our aim was to summarize the research that has been conducted to gain a comprehensive understanding about *how olfactory impairments impact close social relationships*. We examined 3 types of close social relationships: family, friend, and romantic. Our review highlighted several avenues by which olfactory impairments may impact close social relationships. First, heightened social insecurities related to olfactory impairment, often due to hygiene concerns, can create barriers for the formation of new social relationships and engagement in sexual activities. Secondly, reduced ability to detect scent-based information from social partners could reduce perceptiveness with negative consequences for relationship formation and maintenance. Finally, scent-cued bonding and stress buffering benefits are not available to people suffering from olfactory impairments. These missed opportunities for scent based social connection may lead to reduced perceptions of social support, decreased relationship satisfaction, and increased stress. Overall, our review indicated that olfactory impairment is likely to have detrimental consequences on close social relationships, however future work is needed to produce direct evidence of many of the hypothesized relationships. Compelling evidence of these relationships is limited, the magnitude of these effects is unclear, samples are generally limited to western populations, and there is likely to be high variability in how people with olfactory dysfunction are affected by their condition.

One source of variability may be whether a person is aware of their reduced olfactory abilities. Interestingly, people with objectively measured olfactory dysfunction sometimes believe they have a normally functioning sense of smell, highlighting the danger of relying on self-assessments of olfactory ability (Boesveldt et al. 2017a). Another recent study examined the olfactory functioning of a group of participants who all believed they had no olfactory impairment (however some of them did have an impairment; Oleszkiewicz et al. 2020). Results comparing people with no knowledge of their olfactory impairment to people with no impairment found the groups did not differ in well-being. Although these results await replication, they imply that some of the deficits experienced by people with olfactory loss may be psychological. With this notion in mind, studies reported in this review are often based on individuals aware of their (in)abilities, as they are based on patient groups at clinics. Whether the same effects exist in individuals with impairment who either are unaware of the impairment, or aware but not interested enough to seek help, should be more thoroughly investigated.

People with olfactory loss may also develop compensatory mechanisms to mitigate many of the negative consequences of olfactory loss. In the same way that people born without sight exhibit increased olfactory function (Rombaux et al. 2010), although questioned to which degree (Sorokowska et al. 2019), people without a sense of smell may develop stronger mastery of their other senses. Indeed, many of the processes involved in close social relationships are multimodal, for example, a recent review suggests that perception of attraction is multisensory (Groyecka et al. 2017). We know of no research directly investigating whether anosmic individuals have heightened auditory or visual abilities, however one pioneering study found that anosmic individuals are able to integrate auditory and visual information better than control participants (Peter et al. 2019). Also, the result indicates that in an identification task, congenital anosmics, but not those who acquired anosmia later in life, are better able to integrate information from multiple senses compared to healthy control participants (Peter et al. 2019). One implication of this relates to identification of a danger source—such as a fire. When identifying a fire humans use several senses—we can see, hear, and smell the fire (hopefully we avoid touching it). An anosmic individual would only be able to see and hear the fire, however their superior sensory integration may allow them to identify the fire just as quickly as a person using all 3 senses.

Another possible compensatory mechanisms at play are trigeminal nerves, which are responsible for face and motor functions, for example chewing and biting. As a result of these movements of tongue and cheek, smells related to food and flavor perception enter the olfactory cleft partly via the retronasal pathway (Bojanowski and Hummel 2012). A decrease of orthonasal olfactory function (i.e., the type of smelling occurring from sniffing mainly covered in this review) does not always co-occur with a decrease in retronasal function (Landis et al. 2005). In a recent study with 178 patients suffering from olfactory loss, the ability to identify flavors (which is related to retronasal olfaction) predicted quality of life measures better than orthonasal olfactory function (Oleszkiewicz et al. 2019). In addition to the perception of flavors, it is also possible that certain compounds of body odor may be partially perceived retronasally and their effects may be somewhat immune to deficits of the main

orthonasal olfactory system. These possibilities highlight the importance of measuring both types of olfactory ability in future research examining the impacts of olfaction on social relationships.

During the COVID-19 pandemic, most people have experienced significant restrictions on the quantity and quality of their social interactions, and in many cases they cannot even see some members of their family and close friends. Since much of the communication currently allowed is virtual, the importance of olfaction is rather downplayed. However, the current shift to online communication in some ways mimics the change a person would experience if they suddenly lost their sense of smell—social communication is still possible however some of the subtle signals and benefits associated with physical interaction (including scent-based ones) are lost. Thus, it may be useful to study coping mechanisms and therapies that have been beneficial for anosmic individuals and apply them more broadly. Indeed, olfactory training interventions seem to help individuals suffering from olfactory impairment of COVID-19 (Kattar et al. 2021; Le Bon et al. 2021). Most people with olfactory dysfunctions seem to be able to lead perfectly normal and fulfilling lives (Croy et al. 2014), so examining how these people cope with their condition could be of considerable current interest.

One limitation of our review was that we combined all olfactory impairments in one single construct. At this point, a review of social relationships and any one type of olfactory condition would be very limited in scope. However, we do recognize that different olfactory impairments might lead to different relationship outcomes. For instance, an olfactory disorder acquired later in life would have a very different psychological impact compared to a congenital olfactory disorder. Those who lost their sense of smell may feel something is "missing" while those with a congenital olfactory disorder would have no comparison and perhaps experience less psychological distress. We look forward to future research or reviews that are able to differentiate how different olfactory impairments impact our close social relationships.

We have reviewed the sparse research available investigating how olfactory impairment impacts close social relationships, and we conclude that there are opportunities to incorporate methods already available in social psychology to improve the design and impact of these studies. Studies often use self-reported questionnaires with rather vague terminology asking participants to report how olfactory dysfunction affects their "social lives" or "quality of life." As suggested by others (Boesveldt et al. 2017a), we agree that self-reported questions concerning olfactory impairments require more consideration and careful validation. At the moment, assessment is generally done using a single item which is not optimal as it is unlikely a single item can fully represent a complex construct such as olfaction (Maclver and Carmines 1981). We hope to see future research validating a longer scale of olfactory functioning which measures multiple components of social functioning. In addition, we suggest that to reveal differences in the trajectory of close relationships containing anosmic individuals (vs. individuals with a normally functioning sense of smell) we could borrow longitudinal study designs already used in social psychology. These designs, such as daily diary methods, where self-reported data are entered each day for several weeks or months, could reveal important differences in how people with olfactory impairment develop and maintain their close social relationships. We are enthusiastic to see future studies that carefully investigate the different aspects of how olfactory impairments impact close social relationships and recommend that future researchers integrate methods from social psychology as well as consider the differences in close social relationships discussed here in order to create more nuanced research questions and interventions.

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