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Alterations of gustatory sensitivity and taste liking in individuals with blindness or deafness

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A R T I C L E   I N F O

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Blindness

A B S T R A C T

Food ingestion is crucial for an organism, and eating and drinking are multisensory, complex experiences affected by all functioning modalities. Still, little is known about gustatory perception in blindness and deafness. Empirical studies with this regard have been very scarce and the aim of the current study was to explore whether gustatory compensation may occur like the adjustments observed in other aspects of sensory processing, or if liking of various tastes is affected by blindness or deafness. We hypothesized a decreased gustatory sensitivity and lower liking of all tastes in subjects with hearing disabilities; expected outcomes in the group with blindness were less well justified by the mixed results reported to date. To address the relationship of gustatory sensitivity and taste liking with sensory impairments, we compared the gustatory acuity and liking of bitter, salty, sour and sweet tastes of 100 individuals with blindness and 74 people with deafness with matched control groups without sensory impairments. We found that deafness was associated with lower gustatory sensitivity toward the basic tastes and their decreased likeability, and that blindness predicted an increased sensitivity only towards the salty taste, and just among individuals with an early visual loss. Our results suggest that auditory and visual deficits may undermine food experience and may lead to altered taste liking. Reasons of these outcomes discussed in the current article vary from anatomy to social and economic decisions driving gustatory experience.

1. Introduction

Human perception comprises data from five senses – vision, audition, olfaction, gustation and touch. However, some people are deprived of certain sensory information, either because of a congenital sensory loss, or because one or more of their senses ceases to function at some point during their life. For decades, researchers have investigated the sensory functioning of individuals affected by blindness or deafness. People with blindness were, for example, found to have particularly developed tactile (Goldreich & Kanics, 2003; Legge et al., 2008) and auditory abilities (Doucet et al., 2005; Lessard et al., 1998; Voss & Zatorre, 2012). In turn, deafness may be associated with a selective enhancement in execution of complex visual tasks, especially those involving visual peripheral perception or visual attention (Bavelier et al., 2001; Brozinsky & Bavelier, 2004; Dye et al., 2007; Shiell et al., 2014). Behavioral enhancement in functioning modalities of individuals with a sensory impairment, i.e., *a sensory compensation* (Bäckman & Dixon, 1992), may be driven by several mechanisms. First, it may emerge because of a redistribution of attentional resources, gradually leading to an increased, exposure-related sensitivity (Gagnon et al., 2014). Second, differential functioning of the other sensory or higher-order cognitive functions (Gougoux et al., 2005; Striem-Amit et al., 2012) may cause an improvement in some of the functioning senses. Finally, researchers have hypothesized that sensory compensation may also result from a combination of such peripheral and central factors (Kupers & Ptito, 2014).

While both visual and auditory information are important for social communication, or for a detection of potentially dangerous events, it is

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also crucial that they support eating behaviors. Sight can guide food search and selection and may affect flavor perception (for a review see (Spence, Levitan, Shankar, & Zampini, 2010). Audition, although less obviously involved in our ingestion, was found to have "*a dramatic effect on our perceptions of food and drink*", including food choice, preferences and consumption (Spence & Shankar, 2010). Recently documented cross-modal correspondences between basic taste and voice qualities further advocate for the role of auditory information in shaping gustatory experience (Motoki et al., 2022). Thus, is taste function altered in individuals with blindness or deafness? Provided the importance of gustatory function and possible, training-induced plasticity of the gustatory system (Kobayashi et al., 2006; Kobayashi & Kennedy, 2002) it may be expected so, but little is known about gustatory perception in blindness and deafness. Empirical studies with this regard have been very scarce and it remains unclear if gustatory compensation may occur in sensory impairments, mirroring the adjustments observed in other aspects of sensory processing, or whether liking of various tastes is affected by blindness or deafness.

In the case of deafness, available data on gustatory perception are limited to self-assessments, wherein people with a hearing impairment tended to exhibit inflated sensitivity self-assessments across all intact modalities (Pieniak et al., 2020). A similar tendency was observed among people with blindness (Pieniak et al., 2022). However, behavioral evidence for the alterations of gustatory function in people with a visual or an auditory impairment is scarce, and conclusions remain ambiguous. Although taste abilities were found to be enhanced in blindness (Terner et al., 1987), other reports showed no compensatory effects of a visual deprivation (Gagnon et al., 2013; Smith et al., 1993). For example, a series of works by Lea Gagnon and colleagues showed increased thresholds for taste detection and taste identification (Gagnon et al., 2013), as well as a lower activation of the primary taste cortex in people with congenital blindness (Gagnon et al., 2015). Lack of the gustatory compensation in blindness was also supported by the absence of recruitment of the occipital cortex during taste processing (Gagnon et al., 2015). Gagnon and colleagues (2015) attributed their findings to a gustatory underexposure in people with visual impairment resulting from blindness-related obstacles when finding and preparing foods (Bilyk et al., 2009). Indeed, people with a visual impairment were also shown to rely on internal hunger cues when eating (rather than on exposure to, e.g., palatable food) to a higher extent than sighted people (Gagnon et al., 2013). On the other hand, individuals with a visual impairment were shown to be particularly sensitive to various parameters of food, such as aroma, tenderness and juiciness (Damaziak at al., 2019).

In summary, while a conviction on gustatory compensation in blindness and deafness is shared by people with sensory deprivations and intact sensory functioning (Pieniak et al., 2020, 2022), the actual occurrence of a sensory compensation is neither an automatic, nor a straightforward process (Frasnelli et al., 2011). Given very few available reports on gustatory perception in people with sensory impairments, we explored the gustatory acuity and taste liking in large samples of individuals with blindness or deafness and we compared their scores with matched control groups without sensory impairments. Based on the former reports suggesting that the pre-operational compromised gustatory sensitivity can even decrease as a result of cochlear implantation and injury of chorda tympani (Jeppesen et al., 2015; Mikkelsen et al., 2017; Mueller et al., 2007; Walliczek-Dworschak et al., 2018), we expected to find a decreased gustatory sensitivity in subjects with deafness, especially in those with cochlear implants. This was expected for all examined tastes, as the current literature does not allow to propose hypotheses for the altered gustatory sensitivity and liking in auditory loss with regard to specific tastes. In the case of subjects with a visual impairment, we also explored potential differences between the subjects with late and early blindness. The age of a sensory loss can influence subsequent neural and functional reorganization (Striem-Amit et al., 2012), and the only existing, direct evidence for decreased gustatory sensitivity comes from congenitally blind individuals (Gagnon et al., 2013). This scarce knowledge makes it very interesting to explore other aspects of taste perception in people with early blindness, as well as raises new questions on gustatory perception in late blindness. Provided the overall, mixed results on chemosensory performance in blind subjects (Sorokowska et al., 2019; Sorokowska et al., 2020; Sorokowska & Oleszkiewicz, 2022), we propose no directional hypotheses for gustatory thresholds and taste liking, neither in the early blind individuals, nor in people who lost their sight after some years of visual experience.

2. Materials and methods

2.1. Ethics statement

The study was conducted in accordance with the Declaration of Helsinki and all aspects of the study were approved by the Institutional Review Board at the Institute of Psychology, University of Wroclaw. Study protocol was additionally consulted and approved by the Polish Association of the Blind and the Polish Association of the Deaf, and educational institutions for people with visual and auditory deficits. All subjects provided written informed consent and received financial compensation for their participation in the study.

2.2. Participants

Due to our interest in comparing effects of blindness and deafness on gustatory thresholds, the protocol for this study required recruitment of two control groups. Blind subjects had instructions read aloud while deaf subjects received written or sign language instructions. Therefore, to fully control the potential influence of the mode of instruction (protocol), for blind people we recruited a sighted (and hearing) control group and for deaf people we recruited a hearing (and sighted) control group. The two control groups differed only in terms of the instructions mode (protocol). Sample size was estimated with G*Power software (Erdfelder et al., 2009). To be able to detect small-to-moderate effect size ($f = 0.15$) with the power of $\beta = 0.80$ for F-test comparing four groups (df1 = 1) the required sample size was at least 351 subjects.

2.3. Blind individuals and sighted controls

One-hundred and ninety-nine participants (49.7 % females) whose age ranged from 17 to 57 years ($M = 34.1 \pm 10.3$) were invited to take part in this study. 49.7 % had no vision problems ($N = 99$) while the other 50.3 % of the participants ($n = 100$) were blind and based on the onset of their blindness were categorized as early-blind (<2 years, (Rombaux et al., 2010); $N = 49$) or late-blind (>2 years; $N = 51$). Blind people were recruited via the Polish Association of the Blind, Social Support Services, a non-governmental foundation supporting blind individuals and a contact database established in the previous projects. They had marginal ($N = 48$) to no light sensitivity ($N = 52$), and none of the blind participants or sighted controls reported diabetic, neurological, or psychiatric diseases. Blind subjects and their sighted controls were matched in terms of sex distribution, $\chi^2(1) = 1.13, p = .29$ but blind subjects were slightly older ($M = 36.4 \pm 1$ years) than their sighted controls ($M = 31.8 \pm 1$ year), $t(197) = 3.21, p = .002$. For this reason, age was controlled in the subsequent analyses. For demographic characteristic of the study sample see Table 1.

2.4. Deaf individuals and hearing controls

One-hundred and seventy-four individuals (51.7 % females) whose age ranged from 16 to 57 years ($M = 31.0 \pm 11.5$ years) took part in the study. Of these, 57.5 % had normal hearing ($N = 100$), operationalized as the ability to hear below 90 dB and nearly 100 % speech comprehension in speech audiometry and digit triplets test (see below). All deaf participants ($N = 74$) had binaural hearing loss certified with medical

Table 1
Demographic characteristic of the study sample.

	N	*M*(age)	*SD*(age)	% females
Blind	100	36.4	10.1	46
Early blind	49	32.7	8.8	43.1
Late blind	51	40.2	9.9	49
Sighted contols	99	31.8	10.1	53.5
Deaf	74	30.7	11.5	50
No hearing support	31	38.1	9.9	45.2
Cochlear implant	10	19.7	4.2	50
Hearing aid	32	26.5	9.3	53.1
Hearing controls	100	31.1	11.6	53

records and further confirmed in the laboratory by the means of speech audiometry and digit triplets test designed to determine speech recognition thresholds (Masalski et al., 2014; Masalski & Kręcicki, 2013). None of the deaf subjects exceeded 50 % of speech comprehension. Majority of the deaf sample communicated in sign language and the subjects differed in the usage of hearing treatments [unknown ($n = 1$), none ($n = 31$), hearing aids ($n = 32$) or cochlear implants ($n = 10$)]. Nearly 75 % of deaf participants were born without hearing ability (congenital deafness). The remaining 19 subjects lost their hearing in infancy or childhood (mean age of onset 3.47 y ± 2.9 years). Deaf and hearing participants had no diabetic, neurological or psychiatric diseases, and were recruited through the Polish Association of the Deaf, Social Support Services and educational centres for deaf people. Deaf subjects and their hearing controls were matched in terms of sex, $\chi^2(1) = 0.15, p = .70$ and age $t(158.4) = 0.22, p = .83$ (corrected for unequal in-group variance as indicated by the significant Levene's test, $p = .99$).

2.5. Procedure

Prior to inclusion in the study, the subjects completed a detailed medical questionnaire screening for possible health conditions impeding chemosensory sensitivity, including head trauma; pregnancy; diabetes; neurological conditions, smoking, etc. (Welge-Lüssen et al., 2013). Further, their gustatory sensitivity towards four tastes: bitter, sour, salty and sweet was measured with Taste Sprays (Walliczek et al., 2016) – brown glass bottles with atomizer containing solutions of sweet taste: D-saccharose; sour taste: citric acid; salty taste: sodium chloride (NaCl); and bitter taste: quinine hydrochloride, each diluted in distilled water in 6 different concentrations (for the exact concentrations see Table 2). We used Taste Sprays for our perceptual gustatory study since liquids are more effectively perceived than tastants that have to be brought in solution through local saliva, and because sprays are resilient to the effects of xerostomia (dry mouth) on taste perception. Subjects were presented with tastants of increasing concentrations, always starting from the lowest concentration (level VI) and moving towards the highest concentration (level I). At each concentration level (VI-I), tastants (bitter, sour, salty and sweet) were presented in a random order. Subjects were asked to open their mouth, extend their tongue and for each presentation, a tastant volume of approximately 150 µl was sprayed onto the tongue. Afterwards, the subjects were allowed to take their tongue inside the mouth again and to move it in the mouth cavity. The taste had to be identified as either sweet, sour, salty or bitter. After each tastant, subjects rinsed their mouth with distilled water and the following tastant was presented, unless the subject requested a break. The experimenter recorded correct and incorrect scores for all 24 sprays. An individual session lasted for approximately 20 min and was performed at once. Gustatory sensitivity was calculated as the lowest correctly detected concentration of a given tastant. Additionally, when tastants of the highest concentration were applied on the tongue, subjects were asked to rate how likeable the taste is using a Liker-type scale ranging from 1 – not likeable at all to 7 – very likeable.

2.6. Statistical analyses

We used IBM SPSS software v. 27 with the significance level set to $\alpha = 0.05$ in the analyses. Linear mixed models (LMMs) with restricted maximum likelihood (REML) were employed to investigate: (1) lowest detected concentration of a given tastant (gustatory threshold); (2) taste likeability. For the gustatory threshold, we first examined the omnibus model including the effect of the protocol (written or sign language for deaf individuals + hearing controls vs read aloud to blind individuals + sighted controls), sensory impairment (yes vs no) and taste (sweet vs sour vs salty vs bitter) introduced to the model as fixed factors and age added as a fixed covariate. Participant's ID was included as a random factor (Model 1a). The same omnibus model was computed for taste likeability (Model 2a). We further broke the omnibus model into models examining the role of hearing rehabilitation device (none vs cochlear implant vs hearing aid vs control) in gustatory sensitivity (Model 1b) and taste likeability (Model 2b). For the blind subsample we built LMMs to assess the onset of blindness (early vs late vs sighted) on gustatory sensitivity (Model 1c) and taste likeability (Model 2c). Since our main interest was in between-group contrasts, and not the between-tastant contrasts, the latter have been described and visualised in the Supplementary Materials. All statistical coefficients are estimated for the LMMs.

3. Results

3.1. Gustatory sensitivity

Deaf subjects were less sensitive to tastants in comparison to their hearing controls ($p < .001$), but no such contrast was observed between blind and sighted individuals ($p = .37$). Deaf participants had lower overall gustatory sensitivity than blind subjects ($p < .001$), but there was no significant difference between the control groups ($p = .24$). Sensory impaired subjects (with visual or auditory deficits) exhibited lower sensitivity towards bitter taste than the control subjects (seeing and hearing), irrespective of the protocol ($p < .001$), yet this effect was largely driven by the deaf subjects.

Despite the insignificant three-way interaction (likely to occur as an effect of higher sensitivity presented by blind and lower sensitivity in deaf subjects ruling each other out), a closer look at the pairwise comparisons showed that deaf subjects had universally higher gustatory thresholds than their controls (i.e., they exhibited lower sensitivity for bitter: $p < 001$; salty: $p = .001$; sour: $p = .01$; and sweet tastes: $p = .003$). Blind subjects presented an increased sensitivity towards salty taste ($p = .01$) in comparison to their respective control subsample and they were just as good as their controls in detecting other tastes. For all model coefficients see Table 3 and for data distributions across the groups see

Table 2
Six concentration levels for the bitter, sour, salty and sweet tastants.

Substance	Taste	Concentration level					
		I	II	III	IV	V	VI
quinine hydrochloride	Bitter	0.0512/10 g	0.0128/10 g	0.0032/10 g	0.0008/10 g	0.0002/10 g	0.00005/10 g
citric acid	Sour	0.512/10 g	0.128/10 g	0.032/10 g	0.008/10 g	0.002/10 g	0.0005/10 g
Sodium chloride	Salty	2.56/10 g	0.64/10 g	0.16/10 g	0.04/10 g	0.01/10 g	0.0025/10 g
D-saccharose	Sweet	5.12/10 g	1.28/10 g	0.32/10 g	0.08/10 g	0.02/10 g	0.005/10 g

Table 3
The exact coefficients for linear mixed models (described in detail in the Statistical plan section).

Omnibus models			Gustatory threshold		Taste likeability	
	df1	df2	*F*	*p*	*F*	*p*
Intercept	1	367	1049.768	<0.001	938.219	<0.001
Protocol	1	367	49.753	<0.001	14.707	<0.001
Sensory impairment	1	367	18.213	<0.001	26.975	<0.001
Taste	3	1104	24.874	<0.001	367.061	<0.001
Protocol*Sensory impairment	1	367	30.212	<0.001	32.662	<0.001
Protocol*Taste	3	1104	1.549	0.2	4.786	0.003
Sensory impairment*Taste	3	1104	6.439	<0.001	4.992	0.002
Protocol*Sensory impairment*Taste	3	1104	1.497	0.214	6.096	<0.001
Age	1	367	1.784	0.182	5.091	0.025
Hearing device						
Intercept	1	672	2150.66	<0.001	1583.893	<0.001
Hearing device	3	672	23.941	<0.001	102.614	<0.001
Taste	3	672	7.067	<0.001	19.698	<0.001
Hearing device*taste	9	672	2.445	0.01	3.326	<0.001
Blindness onset						
Intercept	1	784	8751.402	<0.001	4878.736	<0.001
Blindness onset	3	784	11.848	<0.001	177.564	<0.001
Taste	2	784	1.332	0.265	0.726	0.484
Blindness onset*taste	6	784	2.03	0.059	2.432	0.025

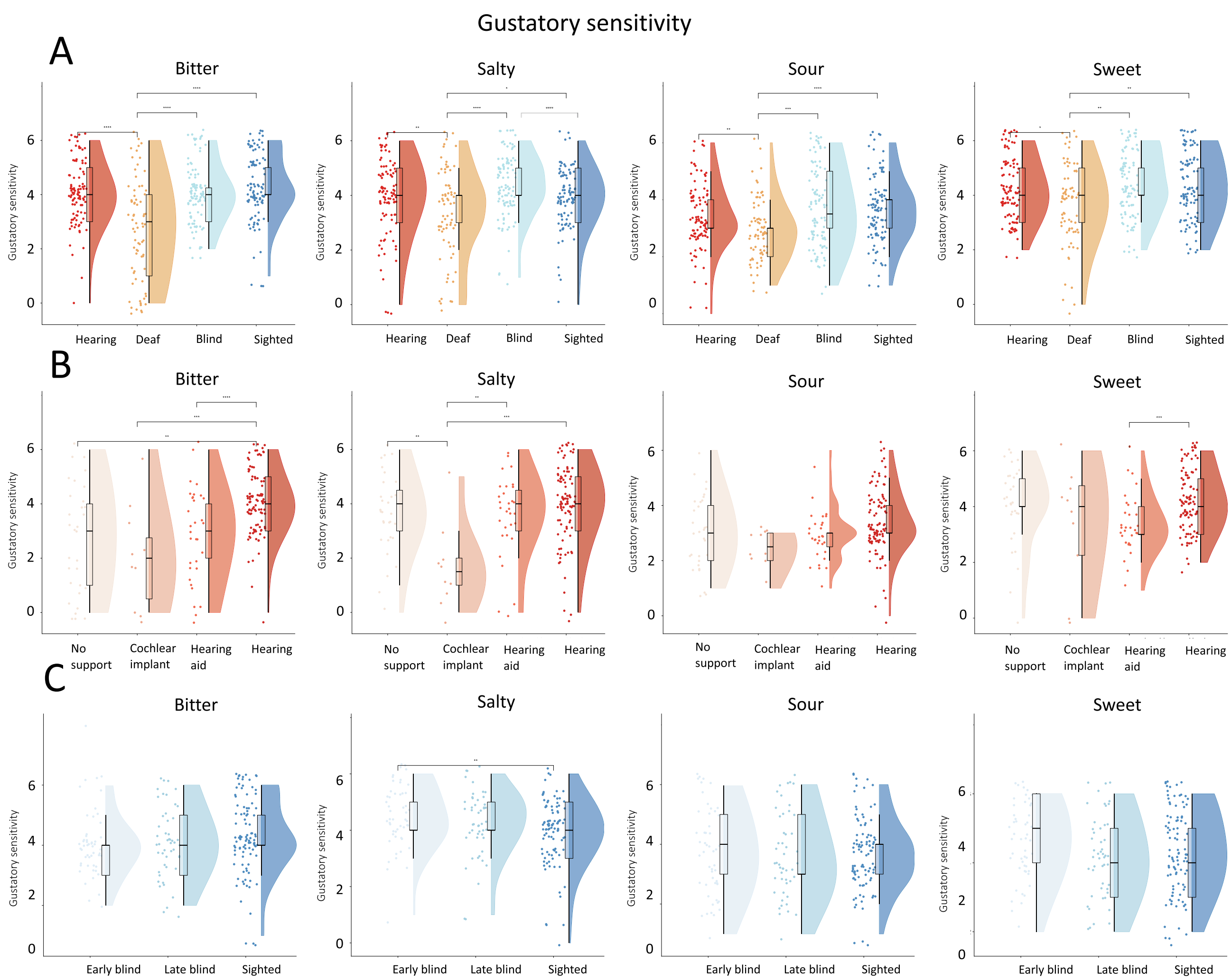

Fig. 1. Data distribution and pairwise comparisons for the gustatory sensitivity across the four tastes. Panel A: Pairwise comparisons for the four study groups: deaf subjects, hearing controls, blind subjects, sighted controls. Panel B: Pairwise comparisons for the three subgroups of the deaf sample based on the hearing support (no hearing support, cochlear implant, hearing aid) and the hearing control group. Panel C: Pairwise comparisons for the two subgroups of the blind sample based on the onset of vision loss (early blind, late blind) and the sighted control group. Note: higher score in the Y-axis indicates higher sensitivity to a tastant (i.e. lower detection threshold).

Fig. 1A.

Given the apparent disadvantage of deaf people in gustatory sensitivity we examined whether a rehabilitation of hearing (i.e., hearing aid or cochlear implant) translates to gustatory sensitivity. We found that all three subgroups of deaf subjects (without any hearing support: $p < .001$; with cochlear implant: $p < .001$; and with hearing aid: $p < .001$) consistently presented significantly lower sensitivity towards bitter taste than their hearing controls. There were no significant differences between the subgroups of the deaf sample with regard to bitter taste sensitivity (all $ps > 0.67$). Interestingly, the subgroup using cochlear implant presented significantly lower sensitivity towards salty taste as compared to a subgroup without any rehabilitation device ($p < .001$), hearing aid ($p = .001$) and hearing subjects ($p < .001$). There were no other significant between-group contrasts in terms of salty (all $ps > 0.93$) or sour (all $ps > 0.12$) tastes. Subjects using hearing aid were significantly less sensitive to sweet taste than hearing controls ($p = .008$) and no other differences reached statistical significance (all $ps > 0.17$) (Fig. 1B).

The onset of blindness marginally interacted with taste sensitivity (see Table 3), indicating that increased sensitivity towards salty taste in blind subjects was mainly driven by the early blind subjects ($p = .023$; Fig. 1C).

3.2. Taste likeability

Along the decreased gustatory sensitivity, deaf people declared lower likeability of bitter ($p = .042$), salty ($p < .001$) and sour ($p < .001$), but not sweet ($p = .62$) taste in comparison to the hearing controls. No differences in taste likeability were found between blind subjects and their sighted controls (all $ps > 0.37$). We noted lower liking of salty ($p < .001$) and sour ($p = .001$), and marginally lower liking of bitter ($p = .054$) tastes in deaf as compared to blind subjects, whereas the control groups differed in the liking of sour taste wherein hearing control subjects liked it more than sighted control subjects ($p = .019$; Fig. 2A).

When looking into the taste likeability in the subgroups of the deaf sample we found that all subjects with hearing impairment (without any hearing rehabilitation device, cochlear implant, and hearing aid) presented significantly lower likeability of salty (all $ps < 0.001$) and sour (all $ps < 0.002$) tastes than their hearing controls. There was no difference between hearing impairment subgroups and controls in the likeability of bitter (all $ps > 0.60$) and sweet (all $ps = 0.1$) tastes (Fig. 2B).

Taste likeability varied as a function of blindness onset. In particular, late blind subjects liked sour taste more than early blind subjects ($p = .007$; Fig. 2C).

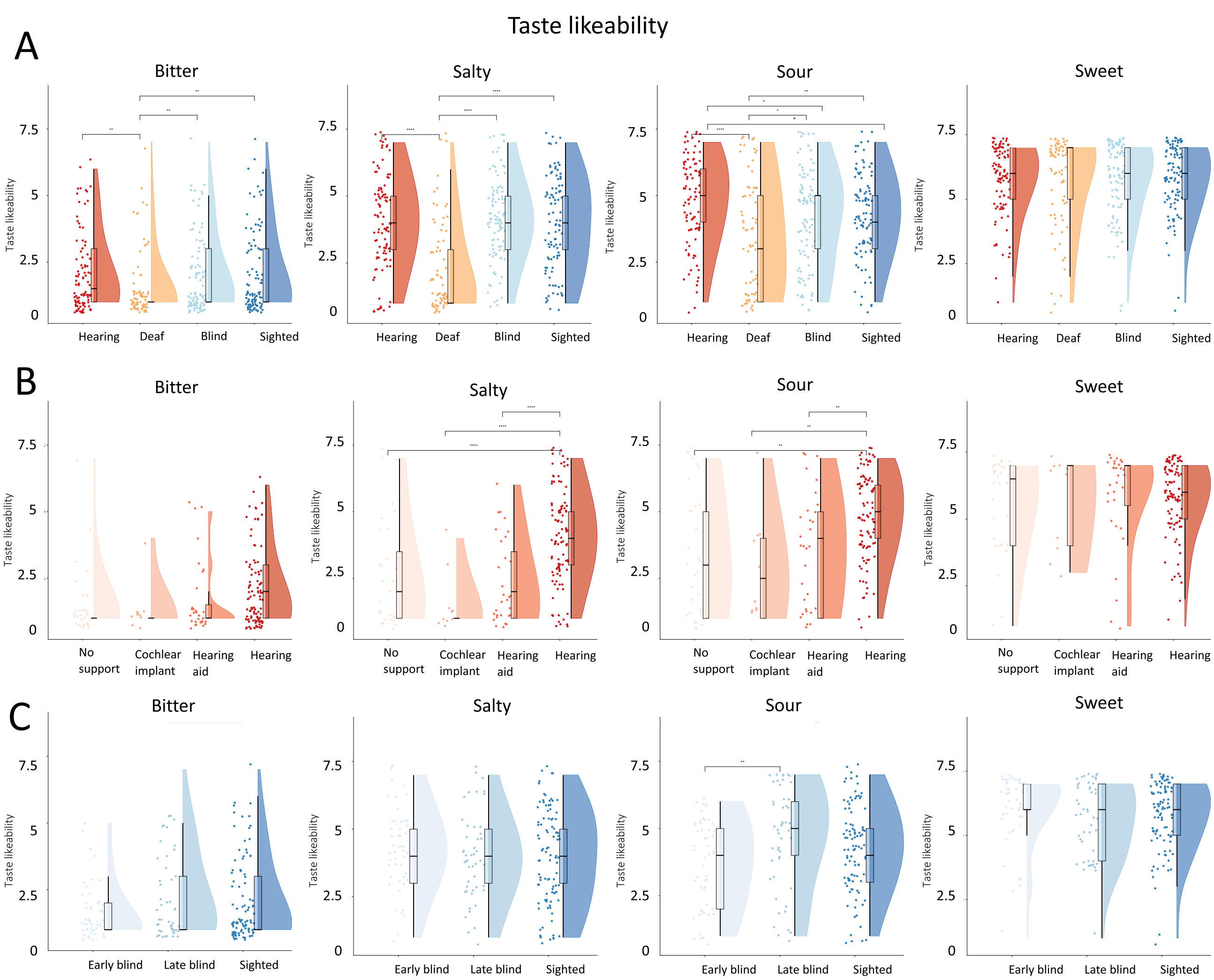

Fig. 2. Data distribution and pairwise comparisons for the taste likeability across the four tastes. Panel A: Pairwise comparisons for the four study groups: deaf subjects, hearing controls, blind subjects, sighted controls. Panel B: Pairwise comparisons for the three subgroups of the deaf sample based on the hearing support (no hearing support, cochlear implant, hearing aid) and the hearing control group. Panel C: Pairwise comparisons for the two subgroups of the blind sample based on the onset of vision loss (early blind, late blind) and the sighted control group.

4. Discussion

Given very few available reports on gustatory perception in people with sensory impairments, we decided to explore gustatory acuity and liking of various tastes in large samples of individuals with blindness or deafness and we compared their gustatory perception with matched control groups without sensory impairments. We found that deafness impeded gustatory sensitivity towards the basic tastes and decreased their likeability, and that blindness was associated with an increased gustatory sensitivity, but only towards the salty taste, and just among individuals with an early visual loss.

Despite the sensory compensation beliefs, commonly present among individuals with and without auditory impairments (Pieniak et al., 2020), hearing impairment was consistently associated with a lower gustatory sensitivity in our sample. The difference was particularly salient for the bitter taste. Together with reports pointing to decreased olfactory abilities in people with deafness (Guducu et al., 2016), and their decreased spatial tactile acuity (Pellegrino et al., 2020; but see Papagno et al., 2016) our results highlight the hindering role of a hearing loss for the functioning of the intact senses by showing the negative consequences of deafness on gustatory acuity and taste liking. At this stage of research, it is difficult to provide any definite conclusions regarding the sources of such an outcome, especially that the ranges of sensitivity scores, as well as of the liking assessments of each taste were additionally rather broad within each tested group. This raises questions about individual predictors that indirectly modulate the gustatory sensitivity and taste preferences, other than a sheer sensory impairment itself. We may speculate that taste experiences, highly dependent on voluntary consumption of various food products, may be less extensive and diverse in people with deafness as compared to the hearing controls. Auditory experiences, although seemingly separate from feeding behaviors, are an important source of information about the food and feeding-related pleasure (Spence & Shankar, 2010). People with deafness, deprived of these stimuli, can be less open to culinary experiences and new foods. Consistent with this reasoning, people with deafness also declared lower likeability of bitter, salty and sour tastes. Gustatory preferences are associated with exposure to various tastes in one's environment (Pieniak et al., 2022; Sorokowska et al., 2017) and many studies conducted among children reported associations between sensory sensitivity, sensory exposure and diet variability (Coulthard & Thakker, 2015; Johnson et al., 2015; Nederkoorn et al., 2015; Wardle & Cooke, 2008). Only the liking of sweet taste did not differ between the people with deafness and hearing controls, but this outcome again provides additional support for the hypothesis on possible, exposure-driven development of food preferences (or lack of thereof) in deaf people, since liking for sweet taste is acquired very early in life (Maone et al., 1990), happens extremely easily (Liem & De Graaf, 2004) and is likely to persist in adulthood (Pepino & Mennella, 2005). In practice, this outcome may mean that people with deafness can be particularly picky/neophobic with regard to their foods and hence vulnerable to malnourishment and other difficulties associated with poor diet. Their decreased taste sensitivity may be also predictive of depressive symptoms (Han et al., 2018). Future studies exploring gustatory acuity and taste liking in the context of sensory loss should account for dietary habits and attitudes towards new food. Additionally, one may speculate that the (possibly) underprivileged economic situation of sensory deprived individuals restrains them from exploring new foods or undertaking activities related to food consumption such as visiting restaurants or food-related events (Świdziński, 2014).

An interesting question arising from the previous reports and our study concerns the role of rehabilitation devices (hearing aids or cochlear implants) on a restoration of gustatory abilities, and conversely – on the effects of a late hearing loss on taste perception. Majority of our deaf sample was congenitally or early deaf, unfortunately limiting generalizability of our conclusions and restraining insights into the role of deafness in gustatory functioning. With regard to hearing rehabilitation devices, our subjects with cochlear implant, hearing aid or no rehabilitation device presented similar gustatory sensitivity (with the exception of sensitivity to salty and sweet) and showed no differences in liking of various tastes. Contrary to former reports (Walliczek-Dworschak et al., 2018), we did not observe a particularly low gustatory sensitivity in subjects with cochlear implants in comparison to the subjects with hearing aid or without any hearing rehabilitation device. However, it should be emphasized that the present study involved a cross-sectional design, whereas evidence for the diminished gustatory sensitivity as a result of cochlear implantation comes from the longitudinal study. At this point we cannot say whether levels of gustatory sensitivity presented by the subjects with cochlear implant are related to the implantation of CI and the functionality of chorda tympani. Thus, it seems that auditory rehabilitation did not affect gustatory function, but to fully confirm this, we would need to know more about the auditory treatment and rehabilitation provided to the subjects. This, however, required longitudinal approach and exceeded the scope of the current investigation.

Blind people in our sample generally exhibited comparable taste sensitivity and taste liking to the sighted controls. Our results are not fully consistent with the previously reported, decreased gustatory sensitivity of people with a visual impairment towards sweet, salty and bitter tastes (Gagnon et al., 2015; Gagnon et al., 2013), and we even found some evidence of a gustatory compensation in this group. Our subjects with blindness exhibited lower thresholds for salty taste detection, although this increased sensitivity towards salty taste in blind subjects was mainly driven by the early blind subjects. Since this was a single result of our study supporting the occurrence of gustatory compensation, it is difficult to assess its predictive value for the overall gustatory compensation mechanism. Nevertheless, these data again show that the sensory compensation is a very complex process that is by no means an automatic consequence of a sensory impairment. Future studies could explore the feeding behaviors and diet of the people with blindness to better understand our outcomes and analyze whether the increased salty taste sensitivity we found in the early blind people could be exposure- and training-related [especially since a central compensatory mechanism for a gustatory function such as cross-modal recruitment of additional cortex seem rather unlikely in blindness (Gagnon et al., 2015)].

Our preliminary study on gustatory sensitivity and taste liking in sensory impairment has some limitations. Taste spray testing is a behavioral measure of gustatory sensitivity and presented results should be supplemented with electrogustometry to fully confirm the reported alterations of gustatory function as a result of visual or auditory deficits. Despite maximizing efforts to standardize oral and written instructions, we also observed a minor difference between the control groups in sour taste likeability ratings. Additionally, the taste sprays we used did not include a umami taste solution. Nevertheless, although umami is a fifth basic human taste, its familiarity in European countries is extremely low (e.g., 2 % of participants in Germany labelled it correctly, Cecchini et al., 2019). Taste familiarity has many potential consequences for its assessments (Prescott, 1998). Therefore, any future studies on taste perception including umami should involve a very careful consideration of the familiarity issue. Finally, liking ratings, although consistently following detection thresholds, were collected only for the highest concentration of each tastant. Such an approach was based on the conviction that the highest concentration assured correct identification of the tastants and a reliable liking assessment. Yet, a deeper insight could have been obtained if liking ratings followed each correct taste identification (irrespective of the concentration). People differ in responsiveness to gustatory stimulation and these individual differences have been linked to hedonic responsiveness to chemosensory stimuli (Piochi et al., 2021). Interestingly, perception of the intensity of gustatory stimuli changes as a function of age (Barragán et al., 2018; Murphy & Gilmore, 1989), which also suggests that more careful monitoring of liking ratings across all concentrations could supplement our understanding of the dynamics of intensity and hedonic perception of taste in sensory impaired groups. Provided the interesting patterns of liking scores in our study, we recommend that future studies exploring this topic pursue a more detailed assessment of taste liking.

Overall, we may conclude that the research on gustatory perception and sensory impairments is an unexplored, yet a fascinating area. Our study has been one of the first projects involving assessments of taste perception in large samples of people with blindness or deafness. Our findings shed some light on possible taste and feeding-related problems associated with sensory loss and stimulate further research questions and hypotheses in this domain.

CRediT authorship contribution statement

Oleszkiewicz Anna: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, Writing – original draft, Writing – review & editing. **Resler Katarzyna:** Conceptualization, Investigation, Writing – review & editing. **Masala Carla:** Investigation, Writing – review & editing. **Basile N. Landis:** Writing – review & editing. **Hummel Thomas:** Conceptualization, Methodology, Writing – review & editing. **Sorokowska Agnieszka:** Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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