



## OPEN Differences in smell and taste performance and food liking between patients with stroke and healthy controls

Catherine Anna-Marie Graham<sup>1</sup>✉, Harry Stevens<sup>1,2</sup>, Francesco Piluso<sup>1,2</sup>, Silvia Camarda<sup>2</sup>, Yiannis Mavrommatis<sup>1</sup>, Paolo Gasparini<sup>1,2,3</sup> & Maria Pina Concas<sup>3</sup>

The impact of olfactory (smell) and gustatory (taste) dysfunction post-stroke is unclear, despite being frequent and detrimental to quality of life. Malnutrition is common post-stroke, with smell and taste deficits being potential contributors. This study aimed to assess whether people who have had a stroke have smell and/or taste deficits, to elucidate any specific deficits including hedonic assessment, and to assess food liking, compared to healthy controls. A 1:3 age- and sex-matched design was employed, including 47 patients with stroke (28–90 years, 29% female), and 141 controls. A higher percentage of patients with stroke were anosmic (50%), thus could identify fewer scents, and were recorded to have a decline taste ability (46.5%), when compared to healthy controls ( $p < 0.05$ ). Concurrent smell deficits and a declined taste ability were also found more frequently in patients with stroke than healthy controls ( $p < 0.05$ ). Lastly, food liking was lower in patients with stroke, with potential influences of smell and taste ability. This study emphasises the breadth of sensory challenges faced by patients with neurological disease, with potential implications on dietary intake. Further understanding of smell and taste deficits could pave the way for targeted rehabilitation strategies and personalised nutritional support.

Neurological disease (ND) can lead to olfactory (smell) and gustatory (taste) deficits<sup>1,2</sup>. The ability to taste and smell enhances environmental interaction, including gastronomical enjoyment, social interaction, and warning for harmful substances<sup>3</sup>. Smell and taste impairments can lead to depression and an increased risk of mortality<sup>4–7</sup>. Some NDs are well understood in this regard, for example smell loss is a known symptom of Parkinson's disease (PD). However, There is a lack of knowledge on the presence and possible impact of smell and taste impairments in other NDs such as stroke, one of the leading causes of disability and death worldwide<sup>8,9</sup>. Stroke is a complex ND with vastly heterogenous physiological outcomes. It has a more acute onset than other NDs, but similar lasting neurological effects in relation to sensory deficits. A large body of research exists specifying stroke prevalence, categorising pathologies, and assessing treatments and rehabilitation methods<sup>10</sup>. The majority of treatment and rehabilitation literature focusses on the loss of mobility; comparatively little literature aims to understand the loss of smell and taste function, despite these being frequent and important<sup>11–15</sup>.

Olfactory assessment, by smell identification, has revealed dysfunction in up to 40% of patients with stroke (PwS) in varying brain locations<sup>16</sup>. Additionally, asymmetric olfactory pathway changes have been documented, with the left olfactory bulb volume decreasing with age and stroke duration<sup>14</sup>, although evidence is sparse and clear conclusions cannot be drawn. Regarding taste, assessments using standardised tests, such as taste strips, show that stroke is associated with measurable taste impairments. Heckmann et al.<sup>11</sup> reports taste dysfunction with damage to the frontal lobe associated with hypogeusia, when compared to other brain areas. Other case studies demonstrate changes in taste ability in diverse regions of brain damage, for example, by cerebral haemorrhage near the left superior cerebellar peduncle<sup>17</sup>, acute left thalamic infarction<sup>18,19</sup>, acute right midbrain and thalamic infarction<sup>20</sup>, and complete left MCA distribution infarct<sup>12</sup>. A 2.4-fold increase in taste dysfunction has also been reported in patients with supratentorial left hemisphere stroke, although in this study deficits were assessed by questionnaire only. Overall, various locations of stroke may impact the ability to taste and smell, and although no clear conclusions can be drawn it can be hypothesised that stroke lateralisation may impact outcome.

<sup>1</sup>Lake Lucerne Institute (LLUI), Rubistrasse 9, Vitznau 6354, Switzerland. <sup>2</sup>Department of Medicine, Surgery and Health Sciences, University of Trieste, Trieste 34149, Italy. <sup>3</sup>Institute for Maternal and Child Health—IRCCS, Burlo Garofolo, Trieste 34127, Italy. ✉email: cat.maher@llui.org

Concurrently, it is frequently acknowledged that malnutrition is common post-stroke<sup>21–23</sup>, and is linked with an increased risk of death or dependency<sup>24</sup>. A decline or loss in smell and/or taste may be a contributing factor to food liking<sup>25</sup>, an important component of dietary intake<sup>26</sup>. Such deficits may lead to an altered<sup>27</sup> or negative<sup>19</sup> dietary pattern, and therefore when assessing taste and smell in ND cohorts, food liking is an important outcome to consider.

All considered, the primary aim of this study was to assess the smell and/or taste ability of PwS in the sub-acute to chronic phase, to elucidate any specific differences including hedonic assessment, and to assess food liking when compared to sex and aged match healthy controls. The secondary aim was to assess possible differences in the aforementioned aims based on type of stroke and laterality.

## Methods

### Participant characteristics

The following inclusion criteria applied to PwS: stroke event older than 30 days (sub-acute to chronic), aged 18+ years, presence of neurological data to determine laterality of stroke, as well as any other clinical routine assessment. The following exclusion criteria applied to PwS: dysphagia grade 3 or above, recent COVID-19 diagnosis (within the past 6 months that has resulted in a loss of taste), and previous physical or neurological condition that caused sustained deficits in smell and/or taste functionality.

### Smell and taste assessment

All data were collected in private rooms, without odour, visual or auditory distractions. Smell identification was carried out using the 12 Sniffin' Sticks test (Burghart Messtechnik GmbH, Wedel, Germany<sup>28,29</sup>). Participants were required to identify the smell (between four options, or no smell). This was selected due to the speed and appropriateness for the clinical cohort<sup>30</sup>. Scents were then grouped for analysis by hedonics as per Liu et al.<sup>31</sup>. Taste identification was assessed using Burghart taste strips<sup>32</sup>. One concentration per taste was used (sweet: sucrose, 0.2 g/mL, sour: citric acid, 0.165 g/mL, salty: NaCl, 0.1 mol/L, bitter: quinine hydrochloride, 0.0024 g/mL). Participants were required to identify the taste (bitter, salty, sour, sweet, or no taste). Participants were instructed by an expert administrator and required to refrain from eating, drinking anything but water, and smoking and not brush their teeth prior to participation.

### Food liking

Food liking was assessed as per Pirastu et al.<sup>33</sup>, for approximately 100 foods and beverages, a 9-Point Likert scale was used: from “dislike extremely” (1) to “like extremely” (9). The mean values of the following food groups were used to establish opinion: Dairy, Fatty, Fish, Fruit, Meat, Sweet, Umami, Vegetables. Individual food components are found in Supplementary Table 1. The reliability of each group was >0.6 (Cronbach alpha function available in R library *psy*).

### Healthy controls

Sex- and age matched healthy controls for each PwS were selected from two Italian populations: Friuli-Venezia Giulia, located in North-Eastern Italy, and Val Borbera, located in North-Western Italy. These populations are part of a research project aimed at the identification of genetic and non-genetic factors involved in common diseases and complex traits, as previously described<sup>34</sup>. The same data collection methods were used for the demographic information, taste and smell assessments, and the food liking questionnaire as within the patient cohorts. The inclusion criteria were: (1) completion of the food liking questionnaire, (2) provision of complete information about the smell and taste test, (3) absence of pathologies or conditions that could impair the senses (e.g. cancers, neurodegenerative diseases or strokes), and (4) matching the age of the patients. The *sample* function of R was used to select healthy controls corresponding to patients according to age and sex, starting from a sample of 1152 individuals<sup>34</sup>.

### Statistical analysis

A descriptive statistical analysis was performed including frequency and percentages for categorical variables, and minimum, maximum, median and interquartile range (IQR) for continuous variables. To assess differences between cohorts, the Wilcoxon Mann-Whitney test for continuous variables and Pearson's Chi-squared test or Fisher's Exact Test for categorical variables were applied. All the analysis were performed using R software version 4.1.2 (R Foundation for Statistical Computing, Vienna, Austria). The significance criterion was  $p$ -value < 0.05. Since the explorative intent of a great part of the study, no correction for multiple testing was applied.

Regarding smell ability, a total score was calculated as the number of correctly identified odours. Based on this, participants were defined anosmic (score ≤ 6), hyposmic (7 ≤ score ≤ 10), or normosmic (score ≥ 11; Hummel et al.<sup>29</sup>). The answer “I do not smell anything” was considered incorrect. Odour hedonics groups were as per Liu et al.<sup>31</sup>: pleasant scents (banana, pineapple, rose, peppermint, cinnamon), neutral scents (coffee, leather, liquorice, orange, lemon), and unpleasant scents (fish and clove). Participants were categorised into low (< 50%) and high (≥ 50%) taste performers within hedonic groupings. The Exact McNemar's test was used to compare the proportion of high/low performers among hedonic groupings within each cohort. Regarding taste assessment, individuals were categorised in “high” and “low” tasters based on the number of correct identifications in the taste test: “high tasters” if they identified at least three substances and “low tasters” otherwise. This cutoff was chosen considering the median age of participants (64 years) and the necessity to avoid misclassifying physiologically age-related reductions in taste sensitivity as pathological. Studies on taste evaluation in the elderly population have highlighted that a high percentage of individuals (over 50%) can identify three or fewer tastes<sup>35</sup>.

Logistic regression models were performed to assess the possible influence of sex, age, laterality and type of stroke on smell and taste functions in PwS. In addition to the intent of evaluating the effects of age and sex,

our aim was to assess possible associations between sensory outcomes and the type of stroke or laterality, while accounting for the potential confounding effects of age and sex. Dependent variables for smell function were: (1) hyposmia/normosmia versus anosmia, (2) pleasant scent high performers versus low performers, (3) unpleasant scent high performers versus low performers, and (4) neutral scent high performers versus low performers. Since only two patients were defined normosmic, two osmia groups were considered: hyposmia/normosmia versus anosmia. Regarding taste function, the dependent variables (1) high tasters versus low tasters and (2) correct identification versus incorrect for each taste, were tested. Then, the relationship between the above-mentioned independent variables and concurrent absence/presence of low smell and taste function were tested through ordinal regression model (*polr* function, MASS R library). The concurrent presence/absence of low smell and taste function was coded as an ordinal variable from 0 to 2.

To explore the possible link between food liking and smell and taste function in PwS three regression models were applied, using the food liking groups as dependent variables and hyposmia/normosmia versus anosmia as predictors (model 1), taste high/low (model 2), concurrent absence/presence of low smell and taste function (model 3). Sex and age were included in each model. The models were also carried out in healthy controls.

## Results

### Sample characteristics: patients with stroke and healthy controls

A total of 47 PwS were included in the study (29% female, median age 64, IQR 23.5), 46 performed the smell assessment, 43 performed the taste assessments and 42 completed the food liking questionnaire. Ten patients suffered a haemorrhagic stroke and 37 an ischaemic stroke, with 13 left and 26 right brain-side (Table 1); all results regarding type of stroke can be found in Supplementary Table 2. Briefly, there was *no difference in age and sex distribution between haemorrhagic and ischaemic and stroke laterality*. No differences were detected in age and sex distribution among type and laterality ( $p$ -value > 0.05). The 141 healthy controls have a similar age and sex distribution ( $p$ -value > 0.05; Table 1). Patients with PD were used as an internal control to verify the results of the diverse stroke cohort with a known ND. No differences were found between the cohorts ( $p$ -value > 0.05; Supplementary Table 3).

### Smell identification

PwS showed a median total correct smell identification score of 6.5 (IQR 5.75), with 50% being defined anosmic (Table 2). PwS had a lower identification score than healthy controls ( $p$ -value < 0.001), a lower percentage of normosmic participants and a higher percentage of anosmic participants (4.3% versus 41.1% and 50.0% versus 9.2%, respectively,  $p$ -value < 0.001; Table 2, Supplementary Table 4).

### Taste identification

Fewer PwS were defined 'high tasters' when compared to healthy controls (53.5% versus 76.6%,  $p$  < 0.05; Table 3). Sweet taste was identified most frequently by PwS (83.7%), followed by salty (58.1%), then bitter and sour (55.8%). For sour, the percentage was lower than that of the healthy controls (90.8%,  $p$  < 0.001).

Additionally, there were differences in the distribution of answers between PwS and healthy controls for sour and salty (Supplementary Table 5,  $p$  < 0.05). The most frequent incorrect response for PwS to sour was salty (20.9%) then bitter (14.0%). Regarding salty, the most frequent incorrect response was bitter (20.9%) then sour (16.3%).

### Concurrent smell and taste ability

A greater percentage of PwS had concurrent declined taste ability and smell deficits when compared to healthy controls ( $p$ -value < 0.05, 26.2% versus 3.5%; Fig. 1 and Supplementary Table 6). Notably, all PwS with both anosmia and taste loss has suffered an ischaemic stroke.

#### Risk factors for lower performance

Regression models were performed to identify possible protective/risk factors for lower smell and taste performance in PwS (Table 4). Regarding smell identification, no effect of age, sex, type or laterality was found when categorising patients into osmia groups (hyposmic/normosmic versus anosmic). When hedonic groupings were assessed, for pleasant scents, ageing and left laterality were risk factors for poorer performance (OR 1.1 and 6.5, respectively,  $p$  < 0.05). Regarding taste performance, no effect of stroke type nor laterality was found. Male

	Stroke	HC
	All	All
N (%)	#47 (100%)	141 (100%)
Female, N (%)	14 (29.8%)	42 (29.8%)
Age (years)	28–90	28–89
Min – max	64.0 (23.5)	64.0 (20)
Median (IQR)		

**Table 1.** Sample characteristics of patients with stroke and healthy controls. IQR interquartile range, N participant number. Wilcoxon Mann-Whitney test for continuous variables and Pearson's Chi-squared test or Fisher's Exact Test for categorical variables showed. #One individual had a bilateral stroke, four in the midbrain, and for three the information is not available.

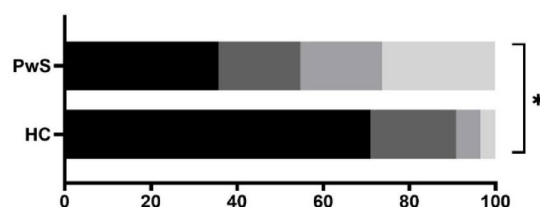
	Stroke	HC	
	All (n = 46)	All (n = 141)	P-value Stroke-HC
Total score			
Min – max	3–12	3–12	<b>0.001</b>
Median (IQR)	6.5 (5.75)	10.0 (3.0)	
Osmia groups, N (%)			
Anosmic	23 (50.0%)	13 (9.2%)	< <b>0.001</b>
Hyposmic	21 (45.7%)	70 (49.6%)	
Normosmic	2 (4.3%)	58 (41.1%)	
Hedonic groups* high performers, N (%)			
Pleasant	29 (63.0%)	122 (86.5%)	<b>0.001</b>
Neutral	25 (54.3%)	125 (88.7%)	< <b>0.001</b>
Unpleasant	40 (87.0%)	140 (99.3%)	<b>0.001</b>

**Table 2.** Smell identification in patients with stroke and healthy controls. *Haem* Haemorrhagic, *HC* healthy controls, *Isch* ischaemic. The total score is the number of correct identifications in the smell test. Participants were defined anosmic (score ≤ 6), hyposmic (7 ≤ score ≤ 10), or normosmic (score ≥ 11; Hummel et al.<sup>29</sup>).

\*Pleasant scents: banana, pineapple, rose, peppermint, and cinnamon; neutral scents: coffee, leather, liquorice, orange, and lemon; unpleasant scents: fish and clove (Liu et al.<sup>31</sup>). High performers: individuals able to identify at least the 50% of odours. The p-value columns are referred to the Wilcoxon Mann-Whitney test. Significant values are in **bold**.

	Stroke (n = 43)	HC (n = 141)	p-value, stroke-HC
HT, N (%)	23 (53.5%)	108 (76.6%)	<b>0.006</b>
Sweet, N (%)	36 (83.7%)	122 (86.5%)	0.624
Salty, N (%)	25 (58.1%)	128 (90.8%)	< <b>0.001</b>
Bitter, N (%)	24 (55.8%)	90 (63.8%)	0.373
Sour, N (%)	24 (55.8%)	86 (61.0%)	0.596

**Table 3.** Taste identification test in patients with stroke and healthy controls. *Haem* Haemorrhagic, *HC* healthy controls, *HT* high tasters, *Isch* ischaemic *N* participant number. P-values were obtained by Fisher's Exact test; Significant p-values are in bold. High tasters: at least three tastes correctly identified.



**Fig. 1.** Percentage of patients with stroke and healthy controls with concurrent declined taste ability and smell deficits. *Ano* anosmia, *Haem* Haemorrhagic, *HC* healthy controls, *Hypo* hyposmia, *High*, high taster status, *Low* low taster status, *Normo* normosmia, *PwS* patients with stroke. \*Significant p-values < 0.05, assessed using the Fisher's Exact Test.

sex was a risk factor for a low taster status (identification of ≤ 1 taste, OR 56.8,  $p < 0.05$ ), and for lower bitter identification (OR 9.5,  $p < 0.05$ ).

When concurrent smell and taste performance were assessed, ischaemic stroke was a risk factor for concurrent low taste and smell function, together with male gender and aging (OR 16.1, 22.27 and 1.07, respectively,  $p < 0.05$ ).

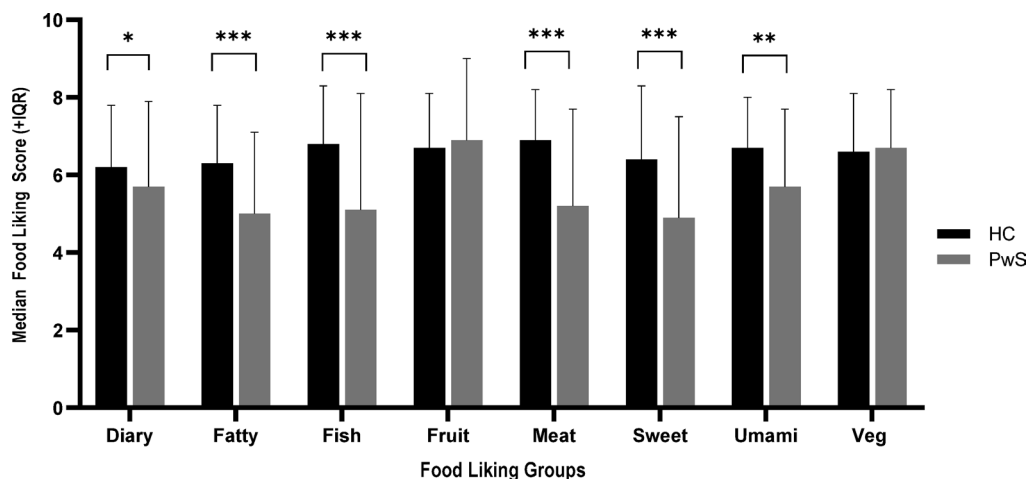
### Food liking assessment and the relationship with smell and taste performance: comparison with healthy controls

PwS had a lower liking for dairy, fatty foods, fish, meat, sweet, and umami, when compared to healthy controls ( $p < 0.05$ ; Fig. 2 and Supplementary Table 7).

As exploratory analysis, the influence of smell and taste function on food liking was assessed (Supplementary Table 8). Anosmic PwS reported a lower liking for sweet and dairy foods, compared to hyposmic and normosmic

Dependent variables	Predictors OR [95% confidential interval] <i>p</i> -value			
	Gender, male	Age	Type, Ischaemic	Laterality, left
a) Smell function*				
Hyposmic/normosmic vs. anosmic	3.0 [0.6;18.1] 0.194	1.1 [1;1.1] 0.085	4.2 [0.6;49.1] 0.192	4.4 [0.9;32] 0.096
Pleasant scents (High vs. low performers)	3.0 [0.6;20.3] 0.224	<b>1.1 [1;1.1] 0.044</b>	2.4 [0.3;28.9] 0.426	<b>6.5 [1.2;47.2] 0.040</b>
Neutral scents (High vs. low performers)	1.2 [0.3;5.7] 0.822	1.0 [1;1.1] 0.280	1.2 [0.2;7.9] 0.877	1.9 [0.4;9] 0.421
b) Taste function				
High tasters versus Low tasters#	<b>56.8 [4.9;2058.2] 0.006</b>	1.1 [1;1.2] 0.055	17.8 [1.1;970] 0.087	1.4 [0.1;11.7] 0.766
Sour, incorrect identification	2.2 [0.4;14.6] 0.376	1.0 [1;1.1] 0.263	4.1 [0.5;95] 0.260	1.2 [0.2;7.6] 0.833
Salty, incorrect identification	6.0 [1;53] 0.067	1.0 [1;1.1] 0.481	5.9 [0.6;141.3] 0.163	0.9 [0.1;5.5] 0.918
Bitter, incorrect identification	<b>9.5 [1.5;94.5] 0.029</b>	1.1 [1;1.1] 0.095	2.5 [0.3;31.6] 0.436	0.9 [0.1;5.3] 0.886
Sweet, incorrect identification§	1.1 [0.1;24.7] 0.951	1.0 [0.9;1.1] 0.576	-	2.2 [0.2;62] 0.562
c) Concurrent smell and taste performance				
Concurrent low smell and taste	<b>22.27 [3.54–197.9] 0.002</b>	<b>1.07 [1.02–1.14] 0.013</b>	<b>16.1 [1.79–262.46.79.46] 0.026</b>	0.53 [0.09–2.64] 0.445

**Table 4.** Logistic regression models for (a) smell and (b) taste function, and (c) ordinal regression models for concurrent low smell and taste function in people with stroke. High taster; at least three tastes correctly identified. Significant associations are in bold. \*For unpleasant scents the model was not performed due to the difficulty to obtain reliable confidence intervals. As shown in Table 2, all strokes that were ischaemic and of left laterality were high performers, and in addition all the females were high performers. Regarding sweet taste, type of stroke was not included in the model due to the number of participants with haemorrhagic stroke showing incorrect identification was too low to obtain reliable confidence intervals (see Table 3 for details).



**Fig. 2.** Median (IQR) for food liking groups in patients with stroke and healthy controls. *Haem* Haemorrhagic, *HC* healthy controls. *P*-value refers to Wilcoxon test. \**p*-value < 0.05, \*\* *p*-value < 0.01, \*\*\* *p*-value < 0.001.

PwS (beta  $-0.92$  and  $-1.2$ , respectively,  $p < 0.05$ ). A similar effect was observed in healthy controls but for fruit and dairy liking (beta  $-1.0$  and  $-1.3$  respectively,  $p < 0.05$ ). No significance was found regarding the effect of taste function on food liking ( $p > 0.05$ ). Lastly, when concurrent dysfunctions were tested, no significant results were detected in PwS, while in healthy controls concurrent dysfunction was associated with a lower liking of dairy foods, fish and fruit (beta  $-1.57$ ,  $-1.62$ , and  $-1.26$ , respectively,  $p < 0.05$ ).

## Discussion

This project aimed to assess whether PwS suffer from a declined smell and/or taste ability, to elucidate any specific differences including hedonic assessment, and to assess food preferences, when compared to healthy controls. A higher percentage of PwS were anosmic and thus were able to identify fewer scents than healthy controls. PwS were able to identify fewer tastes than healthy controls, with common errors apparent. Concurrent smell deficits and a declined taste ability were also found more frequently in PwS than healthy controls. Additionally, analysis revealed that age and left laterality were risk factors for lower odour identification performance regarding hedonic groupings, and all concurrent deficits were in ischaemic strokes, despite the diverse ischaemic stroke phenotype included. Therefore, these factors were predictors for concurrent losses along with sex and age. Lastly,

food liking was lower in PwS when compared to healthy controls, with some potential influence of taste and smell ability.

This study reports smell dysfunction in PwS, consistent with previous findings<sup>14,16</sup>. Using standard smell identification assessments, we demonstrate that deficits are broad. The inclusion of diverse stroke phenotypes supports a non-localised or multifactorial basis for smell<sup>36</sup> and taste function, comparable to Wehling et al.<sup>16</sup>. However, mechanisms underlying these deficits remain unclear. Kültür et al.<sup>14</sup>, using functional magnetic resonance imaging, concluded that both central and peripheral olfactory pathways were impacted post-stroke, potentially due to ongoing inflammation and degenerative changes. Moreover, our exploratory analysis revealed that age and left laterality were risk factors for lower odour identification performance, specifically for a reduced ability to identify pleasant scents. Left hemisphere activity has been correlated with pleasant and unpleasant emotional judgement, by use of olfactory stimuli<sup>37</sup> and the left cuneus has been associated with olfactory naming<sup>38</sup>. However, given the lack of mechanistic clarity, the vast array of brain regions that have been associated with olfaction<sup>36</sup>, and the known unreliability of patient self-awareness to olfactory dysfunction<sup>15,39,40</sup>, further research is needed to understand neurological changes in olfactory deficits, which will guide rehabilitation and treatment strategies.

Further, this study demonstrates that PwS identified fewer tastes than healthy controls, although evidence remains limited and inconclusive<sup>41</sup>. Dutta et al.<sup>12</sup> reported severe taste deficits occur when brain injury is related to taste regions. Yet, in keeping with our results, other studies have reported a declined taste ability related to wider areas of brain damage<sup>17–20,42–44</sup>. These findings support heterogeneous aetiology. Phenotypical variation, however, requires further investigation into specific deficit types. This could be achieved using more comprehensive taste assessments, for example multiple concentrations<sup>32</sup>, offering a more comprehensive sensory profile<sup>28</sup>. Additionally, PwS showed increased misidentification of salty as sour or bitter, a novel finding. Similar confusions have been linked to head trauma, although trauma type was unspecified and comparisons lacked healthy controls<sup>45,46</sup>. Given salty taste's role in increasing dietary intake<sup>47</sup>, and dysgeusia's impact on reducing quality of life and subsequently leading to malnutrition<sup>15,48,49</sup>, a greater understanding across ND types is essential for prevention and treatment developments.

Olfaction and gustation are independent sensory pathways, yet they result in intertwined sensory experiences<sup>50</sup>; thus, concurrent deficits were assessed. PwS showed a higher frequency of concurrent dysfunction than healthy controls, observed exclusively in ischaemic stroke cases. While no directly comparable literature exists, case reports of taste loss are predominantly infarct-related<sup>12,19,44</sup>, despite both infarct and haemorrhage causing tissue death. This study assessed global deficits; however, findings highlight the need for further research into sensory differences between ischaemic and haemorrhagic stroke.

Lastly, PwS reported lower general food liking than healthy controls, except for in the fruit and vegetable groups. Similarly, Kim and Choi<sup>27</sup> documented altered preferences for meats, kimchi, and fish in four cases, and, Green et al.<sup>43</sup> reported heavy salting or sweetening of food to mask distorted tastes in two stroke cases, contributing to comorbidities. Additionally, larger studies suggest smell and taste deficits influence food liking, although details remain unclear and results, are often subjective<sup>11,51</sup>. Our exploratory analysis indicates a possible association between osmia group and food liking, warranting replication in a larger cohort, incorporating objective methods of food liking and dietary assessment<sup>52</sup>.

This study provides valuable insights into the olfactory and gustatory deficits, and food liking, within PwS. For smell assessment, threshold, discrimination, and identification (TDI) tests are often used to diagnose hyposmia and anosmia<sup>53,54</sup>. However, due to the complexity and participant burden of TDI testing, identification tests like in this study, although less comprehensive<sup>28,55</sup>, are more feasible in clinical cohorts<sup>53</sup>. A high correlation between olfactory detection sensitivity and identification ability has validated the use of identification tasks to assess hyposmia and anosmia<sup>56</sup>. It must be noted traditionally tests are forced choice, and do not include a “no smell” option, which should be considered in future research. Further, a much smaller body of research exists in relation to taste<sup>53</sup>. As in this study, taste function is assessed efficiently using impregnated taste strips but future research may use multiple taste concentrations to strengthen the conclusions drawn<sup>32</sup>. Additionally, the food liking data included are self-reported and subjective, which may have limited accuracy and can be subject to bias<sup>52</sup>, and although a determinant of dietary intake it is not a direct measurement, therefore further exploration is warranted utilising more in depth dietary assessments. Lastly, although the within stroke group analysis and separately the assessment of olfaction and gustation on food liking revealed hypothesis driving findings, further research is required on larger sample sizes for conclusive results. Considering this, no correction for multiple testing were applied, and it must be acknowledged that within clinical cohorts, mental and oral health, and other factors such as medication use must also be considered as confounders, if such data is available.

## Conclusions

This study demonstrates the presence of impairments in smell and a declined taste identification ability and differences in food liking in PwS when compared to healthy controls. The results emphasise the breadth of sensory challenges faced by patients with ND, with potential implications on dietary intake. These findings not only contribute to a heightened risk of malnutrition but also highlight the importance of further research and interventions aimed at rehabilitation, which could pave the way for targeted rehabilitation strategies and nutritional support tailored to the unique needs of these patients. Additional studies, using larger patient cohorts, are required to further confirm and expand the present preliminary findings.

## Data availability

Data is available upon request to the corresponding author.

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## Author contributions

Conceptualisation, C.A.-M.G, M.P.C, P.G.; Methodology, C.A.-M.G, M.P.C, P.G.; Material preparation and sample/data collection, C.A.-M.G, H.S, F.P, S.C.; Formal analysis, M.P.C.; Writing, original draft preparation, H.S, F.P, C.A.-M.G, Y.M, M.P.C.; Writing, review and editing, C.A.-M.G, M.P.C, Y.M., P.G; Supervision, P.G.; Funding acquisition, P.G.

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## Declarations

### Competing interests

The authors declare no competing interests.

### Informed consent

Informed consent was obtained from all subjects involved in the study.

### Institutional review board

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Ethikkommission Nordwest- und Zentralschweiz (2023–01441; patients) and the ethical committees of San Raffaele Hospital and IRCCS Burlo Garofolo (Prot. CE/V-78, 06/08/2007, healthy controls).

### Additional information

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**Correspondence** and requests for materials should be addressed to C.A.-M.G.

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