RESEARCH ARTICLE

Flavor perception of wine is unchanged during commercial flight: a comparative field study [version 1; peer review: awaiting peer review]

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Abstract

Background: It is generally accepted that the human perception of flavor and odor is altered in low-pressure environments such as airplane cabins. This has been demonstrated in several simulation studies, but never in a field study conducted in an authentic environment, and never using wine as the object of study.

Methods: We performed a comparative field study composed of two wine tastings. The first tasting was conducted on board an aircraft flying at standard cruising altitude and the second tasting was conducted at ground level. Subjective taste experience and current mood were evaluated through a validated questionnaire. The study was reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guideline.

Results: The study included 22 participants, none of whom had any special training in wine tasting. No statistically significant difference in experienced flavor intensity was found between the high and low altitude tests, with median aromatic intensities of 5 (interquartile range 3.5-6.0) and 5 (interquartile range 4.0-6.5) respectively, measured on a 9-point hedonic scale. Additionally, there was no detectable difference in several other taste parameters.

Conclusions: These findings suggest that even though experimental studies have demonstrated that senses of taste and smell may be suppressed on commercial flights, the subjective wine tasting experience of non-professionals in real life testing may not be affected.

Keywords
Sensation, Gustation, Aviation, Oenology, Wine, Taste, Aircraft, Low pressure environment, Sense of taste
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Introduction

Modern air travel is a multi-billion-dollar industry and more than four billion passengers flew on commercial airlines in 2017, which generated an industry-wide revenue of 755 billion USD\(^1\). Labor, fuel, and equipment are the three biggest running expenses of the industry, but airline catering is also a costly venture, estimated to constitute an average of 2–3% of total operating costs\(^2\). Despite this, airplane meals generally have a poor reputation among passengers. This may be due to the sheer quality of the food, but could also be a result of altered perception of flavor and odor in an airplane cabin\(^3\)–\(^5\).

Food perception is a complex multisensory experience depending on both taste, smell, and mouthfeel, which collectively form an impression of flavor\(^6\). Simulation studies have suggested that our sense of taste and smell is generally reduced in low-pressure environments such as airplane cabins, diminishing the perception of flavor intensity of food products\(^7\)–\(^10\). This is thought to be caused by elevated sensory thresholds for detection of tastants in low-pressure environments\(^5\). Moreover, this transitory impairment of the gustatory and olfactory senses may impair the general enjoyment of food as well\(^7\). In addition to the low air pressure, several other factors present in a standard commercial airline cabin are also assumed to contribute to this, such as dry recirculating air, cold temperature, and low oxygen levels\(^5\),\(^8\)–\(^9\). While the exact physiology behind these phenomena is not definitively determined, some explanatory mechanisms have been suggested: cold and dry air are impeding the interaction between odorants and olfactory receptors, and low oxygen levels are inducing hypoxia which may modulate receptor functioning\(^8\),\(^11\). Other sensory modalities (e.g. hearing) can also impact flavor perception – a phenomenon known as crossmodal correspondence – and in this regard, the constant background noise in an airplane cabin may be another important sensory influence\(^10\),\(^12\)–\(^15\). Psychological stress is also assumed to modulate flavor perception to some degree\(^16\),\(^17\), and commercial air travel is a source of – perhaps minor – psychological stress\(^18\),\(^19\). Clearly, flavor perception during flight is a multifactorial process that has not yet been sufficiently characterized, which is ultimately to the disadvantage of the end consumer.

Wine has a complex composition of flavors and wine tasting requires a special attention to nuance. Therefore, the perception and appreciation of wine may also be affected by the suboptimal conditions in an airplane cabin. In current literature, the specific mechanisms of this process have not been described in its entirety and not all details are fully understood. In Figure 1 we propose a simplified theoretical framework illustrating how these factors may interact and how environmental and individual factors modulate the process of forming a wine consumption experience. Simulation studies have heavily suggested that wine consumption experience is negatively affected during flights\(^8\)–\(^10\), and reportedly, the bitterness of wine is more prominent when consumed in the air\(^5\). However, to the best of our knowledge, the impact of airplane cabin conditions on wine consumption experience has not yet been tested in a field study. In this study, we elected to focus specifically on the concept of flavor intensity and the subjective perception of this.

We hypothesized that the subjective perception of flavor intensity of wine is reduced while on board a commercial aircraft flying at standard cruising altitude compared with on the ground. Furthermore, we speculated that this would lead to a decreased overall liking and appreciation of wine, likely resulting in a worse consumer experience. To test these pre-specified hypotheses, we performed a comparative field study of high and low altitude wine tastings, and we aimed to verify the discrepancy in taste sensation, as suggested by simulation studies.

Methods

Study design

The present study was reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guideline\(^20\) and was performed as a single-blinded, non-randomized field study. The study was carried out in May 2019 and all participants were healthcare professionals (medical doctors, nurses, or medical students) travelling from Denmark to Turkey to attend a scientific conference. Participants were enrolled in February 2019 and all conference attendees

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**Figure 1.** Theoretical framework proposal.
were eligible for inclusion in the study. Potentially eligible participants were excluded from the study if they were reluctant to consume alcohol, if they were pregnant or breastfeeding, or if they had a history of dysosmia or dysgeusia (i.e. olfactory or gustatory dysfunction).

During the experiment, all participants taste-tested two separate samples of the same wine. The wine samples were distributed to the study participants in two transparent Corning™ Falcon 50 mL Conical Centrifuge Tubes (outside diameter: 30 mm; length: 115 mm). Each tube contained only 25 mL of wine, which corresponds to approximately one-sixth of a standard serving size. This conforms to general wine tasting standards and is generally considered sufficient for a simple taste assessment[1]. The participants were carefully instructed (verbally and in writing) to open the plastic tube and let the wine oxygenate for 60 seconds before drinking the sample directly from the container. Each participant consumed either red or white wine according to personal preference. The red wine of choice was the Majestik Syrah & Kalecik Karasi, 2017 (alc. 13.5%), and the white wine was the Majestik Sauvignon Blanc & Sultaniyve, 2017 (alc. 12.5%). Both wines are produced by Sevilen Group, Izmir, Turkey (http://www.sevilengroup.com/en). These wines were chosen as they were the only wines available for purchase on the flight, and because consumption of alcoholic beverages not purchased on the flight was not permitted. Participants were blinded as to the name and production year of the wines, in order to reduce bias[2].

At the first tasting the participants were instructed to fill out a form on basic demographic data and a 12-item questionnaire. The first tasting was conducted on board a Boeing 737–800 (73H) aircraft, which is a short- to medium-range, narrow-body jet airliner that seats 189 passengers and is part of the Boeing 737 Next Generation series. The taste-testing commenced approximately 1h 45m after take-off at an altitude of approximately 37,000 ft (11.278 m) above sea level, which is considered standard cruising altitude. Due to the severe security restrictions on commercial aircrafts, we were not allowed to bring measurement equipment onboard the plane. Therefore, we can only provide a general estimate of the cabin pressure: Aircraft pressurization systems always maintain a cabin pressure above 750 hPa, equivalent to a maximum cabin altitude (i.e. the equivalent altitude with the same air pressure inside the cabin according to the International Standard Atmosphere) of 8,000 ft (2,438 m)[3]. However, when accounting for the Boeing 737–800’s maximum pressure differential[4], the actual cabin pressure would have been between approximately 750 and 790 hPa. This corresponds to a cabin altitude between 6,650 and 8,000 ft (2,027 to 2,438 m).

The second tasting was performed at ground-level, where the participants were asked to fill out the same questionnaire again. This took place en-route to the hotel on board the airport shuttle bus, an Isuzu Novo Lux, which is a medium-sized coach that seats 25 people. The time of tasting was approximately 1h after landing and the altitude was approximately 305 ft (93m) above sea level. In May of 2019 the average air pressure in Izmir, Turkey was 1013 hPa[5].

Our primary outcome was the difference in experienced flavor intensity between high and low altitude testing. The secondary outcomes included differences in the overall liking of the wine and differences in the various other subjective taste parameters.

Questionnaire

We developed and face validated a 2-part questionnaire for this study. The first part was given before taste-testing and concerned basic demographic data and self-assessed wine-tasting expertise on a scale from 1–9 (“poor” to “outstanding”). Part two was given after taste-testing and contained seven items regarding the wine, including overall liking, as well as five items concerning current mood. The questionnaire was developed based on flavor descriptors hand-picked from the literature[6]. Two additional items on subjective drinkability were included (“chugability” and “inebriating effects”), and four items considered relevant to this study was incorporated from the validated Profile of Mood States for Adolescents (POMS-A) questionnaire[7]. For the seven items regarding wine, we adopted the widely used 9-point Hedonic Scale[8], the de-facto gold standard for sensory testing[9].

We performed a pilot test using two individuals considered representative of the study population. To ensure face validity, these two individuals consumed two sample of wine in a high- and low-altitude setting, respectively. They were subjected to the questionnaire and subsequently interviewed about comprehensibility, relevance, and feasibility of the questionnaire. The pilot study resulted in only minor revisions of the questionnaire to optimize the flow and comprehensibility, specifically regarding Items 5 and 6. Reliability testing was not performed. The questionnaire is provided as Extended data.

Statistical analysis

Data were analyzed using IBM SPSS Statistics for Windows, Version 22.0 (Armonk, NY: IBM Corp). The study characteristics were described with proportions for categorical data (number (%)), and median with interquartile range for non-normally distributed data. Paired data were compared using Wilcoxon signed-rank test, with P < 0.05 considered significant. Bonferroni correction for multiple comparisons did not significantly affect our results (data not presented), and therefore, the presented results are uncorrected. Missing values (n = 2) were assumed to be missing completely at random and were excluded on a test-by-test basis.

Due to the lack of existing comparable data, we were unable to form any reasonable assumptions about magnitude of the hypothesized difference between taste tests. Therefore, participants were selected through convenience sampling and all eligible attendees at the aforementioned scientific conference were enrolled in the study.

Ethical considerations

All participants gave verbal consent to participate. According to Danish law, the study did not require approval from the Danish Data Protection Agency nor from the local ethics committee (registration number: H-19013122), because the study did not involve an intervention or collection of biometric data.
Results

In total, 22 participants were enrolled in the study. Of these, 45% were females and the majority were below 40 years of age (77%). 86% chose to drink red wine and the remaining participants drank white wine. The characteristics of the study participants are shown in Table 1.

The experienced aromatic intensities at both high- and low-altitude tastings had a median score of 5 on the 9-point hedonic scale (interquartile ranges of 3.5–6.0 and 4.0–6.5 respectively), and Wilcoxon signed-rank test did not demonstrate any statistically significant difference (p = 0.176). The differences between the remaining taste parameters at high and low altitude were also not significant (p-values 0.153 – 0.858). Nor was there any significant difference in the participants’ POMS-A scores at high altitude compared with their scores at low altitude (p-values 0.058–0.705). Among these, there was a non-significant tendency towards a higher level of sleepiness at low altitude than at high altitude (p = 0.058). The results are listed in Table 2.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Number (%) or median (IQR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female sex</td>
<td>10 (45%)</td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
</tr>
<tr>
<td>20–29</td>
<td>9 (41%)</td>
</tr>
<tr>
<td>30–39</td>
<td>8 (36%)</td>
</tr>
<tr>
<td>40–49</td>
<td>4 (18%)</td>
</tr>
<tr>
<td>≥50</td>
<td>1 (5%)</td>
</tr>
<tr>
<td>Self-estimated expertise(^1)</td>
<td>4(3–5)</td>
</tr>
<tr>
<td>Red wine</td>
<td>19 (86%)</td>
</tr>
<tr>
<td>White wine</td>
<td>3 (14%)</td>
</tr>
</tbody>
</table>

IQR = Interquartile range. \(^1\) Self-estimated expertise in wine tasting on a scale from 1–9.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>High altitude Median (IQR)</th>
<th>Low altitude Median (IQR)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wine characteristics(^1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aromatic intensity(^2)</td>
<td>5.0 (3.5–6.0)</td>
<td>5.0 (4.0–6.5)</td>
<td>0.176</td>
</tr>
<tr>
<td>Fruit notes(^2)</td>
<td>4.5 (3.0–6.0)</td>
<td>5.0 (3.0–6.0)</td>
<td>0.795</td>
</tr>
<tr>
<td>Bitterness(^2)</td>
<td>5.5 (3.5–7.0)</td>
<td>6.0 (4.5–6.5)</td>
<td>0.621</td>
</tr>
<tr>
<td>Oak integration(^3)</td>
<td>3.5 (3.0–5.0)</td>
<td>3.0 (2.0–4.5)</td>
<td>0.412</td>
</tr>
<tr>
<td>Inebriating effects(^3)</td>
<td>5.5 (4.0–6.5)</td>
<td>4.5 (4.0–5.5)</td>
<td>0.267</td>
</tr>
<tr>
<td>Chugability(^4)</td>
<td>3.0 (2.0–6.0)</td>
<td>4.0 (2.0–5.0)</td>
<td>0.858</td>
</tr>
<tr>
<td>Overall liking(^4)</td>
<td>3.5 (2.0–6.0)</td>
<td>3.0 (2.5–4.0)</td>
<td>0.153</td>
</tr>
<tr>
<td>POMS-A(^5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Happy</td>
<td>3 (2–3)</td>
<td>3 (2–3)</td>
<td>0.593</td>
</tr>
<tr>
<td>Annoyed</td>
<td>0 (0–1)</td>
<td>0 (0–1)</td>
<td>0.388</td>
</tr>
<tr>
<td>Confused</td>
<td>0 (0–0)</td>
<td>0 (0–0)</td>
<td>0.705</td>
</tr>
<tr>
<td>Miserable</td>
<td>0 (0–0)</td>
<td>0 (0–0)</td>
<td>0.317</td>
</tr>
<tr>
<td>Sleepy</td>
<td>1 (1–2)</td>
<td>2 (1–3)</td>
<td>0.058</td>
</tr>
</tbody>
</table>

IQR = Interquartile range. POMS-A = Profile of Mood States for Adolescents questionnaire.

\(^1\): Ranging from 1 to 9. \(^2\): 1 being “low”, 5 being “neutral”, and 9 being “intense”.

\(^3\): 1 being “poor”, 5 being “neutral”, and 9 being “outstanding”. \(^4\): 1 being “dislike extremely”, 5 being “neither like, nor dislike”, and 9 being “like extremely”. \(^5\): Ranging from 0 to 4. With 0 being “not at all”, 2 being “moderately” and 4 being “extremely”.
Discussion
Among our 22 enrolled participants, the flavor perception and overall liking were unchanged between high and low altitude. Additionally, there was no statistically significant change in participant mood evaluated through the adapted POMS-A questionnaire.

Our findings suggest that lay people do not experience a subjective difference in flavor intensity in a real-life aircraft cabin, when flying at standard cruising altitude compared with at ground level. Furthermore, our study was unable to detect a statistical difference in a variety of taste parameters, including overall liking of wine, fruit notes, and bitterness. This disagrees with multiple simulation studies conducted in controlled environments, simulating the conditions of an aircraft cabin and using test panels of both lay people and gastronomic professionals\(^6\). Our results suggest that even though the gustatory and olfactory senses may be suppressed, it might not affect the subjective tasting experience of lay people (i.e. the final consumer experience) when tested in a real-life setting. Thus, the poor reputation of aircraft cuisine may not be a reflection of a changed perception of flavor and odor in high altitude environments. The mood of our participants was unaffected by the high and low altitude settings. The only parameter of the POMS-A questionnaire that came close to show a statistical difference was the sleepiness of our participants. This can be explained by the late hour of the low altitude tasting and therefore this result is negligible.

A strength of this study is that participants were neither wine professionals nor sommeliers, but lay people with an average knowledge and experience in wine tasting. Thus, the results of this study have high external validity in the general non-wine-proficient population. However, our study population was fairly limited as only 22 participants were eligible for inclusion, and all participants were Danish healthcare professionals making the study population quite homogenous in that regard. Future studies should include a larger and more heterogenous population in terms of nationality, profession, socio-economic status, etc.

This study was conducted in a largely authentic setting, which ensures high ecological validity and makes our conclusions generalizable. In this context, “authentic” refers to a setting that approximates normal circumstances for wine consumption during flight. However, such an uncontrolled study environment does allow for a possible influence of unrecognized and potentially confounding external factors. This is the nature of a field study and the influence of undesirable external factors is inherently unavoidable. It could be argued that the two testing environments in this study were fundamentally different, and in the future, these results could be expanded upon by performing two taste tests in the same airplane cabin, one at cruising altitude and another at ground level. This would reduce the influence of possible environmental confounders. Nonetheless, it could also be argued that the two testing environments in this study were comparable in several aspects. For instance, the presence of constant background noise is quite similar in an airplane cabin and a bus cabin, and the possible influence of auditory-gustatory crossmodal correspondence is therefore not expected to be a significant confounder\(^7,11\). Since we were not allowed to bring measurement equipment onboard the airplane, the exact levels of background noise were not measured and some degree of auditory influence cannot be ruled out. Psychological stress is also thought to have an impact on flavor perception, but as all forms of public transportation can be considered a minor source of stress, the testing conditions were also in this regard quite similar. Psychological stress is therefore not considered a significant confounder in our study.

Some studies have suggested that the five basic flavors (i.e. sweet, sour, salty, bitter, and umami) may be affected differently by the conditions in an airplane cabin\(^13\). Consequently, future studies should include a variety of wines of different characteristics and quality in order to exclude any possible influence of the specific flavor composition of the wines chosen for this study. It may also be interesting to make a similar field study as the present, but including wine experts instead of lay people without special wine tasting abilities or training. It is also recommended that future studies should employ measures to control for confounders related to the individual, such as current satiety, appetite, and thirst. A limitation of the present study is the lack of experimental control. Under optimal circumstances, we would have preferred to implement a randomized crossover design, include a pre-flight taste test, and expand the timeframe in order to reduce the effect of recall bias. Unfortunately, this was not practically or economically feasible given the extensive security restrictions of commercial air travel, which is why we settled on the current experimental design. Another limitation of this study is the use of Falcon tubes as a vessel for the wine, as opposed to normal wine glasses. The experience of drinking a beverage is greatly influenced by the properties of its container\(^6\), and these narrow plastic tubes could be an inhibiting factor in the consumption experience, e.g. inhibiting the odor sensation and diminishing the overall aesthetic experience and its emotional impact on the consumer\(^11,32\).

In general, future research into improving the quality of airline catering could be of great benefit to the industry, as we believe that the current relationship between catering expenses and the quality of the final consumer experience may be disproportionate. The theoretical framework presented in Figure 1 was developed for generating hypotheses and is only intended as a preliminary proposal illustrating the mechanisms at work. It is intended as a basis for further discussion of the topic, and actual testing or validation of the framework is beyond the scope of this article. Further research is necessary on the physiology and psychology of flavor perception onboard airplanes, which will inspire new and innovative methods and techniques for designing meals and beverages optimized for consumption on airplanes. This is part of an emerging field of science known as gastraphysics, which will hopefully pave the way for future improvements in airline gastronomy\(^1\).
In conclusion, we were unable to verify the findings of previous simulation studies, as we did not find a difference in either subjective perception of flavor intensity or overall liking of wine between high- and low-altitude tests. This suggests that any possible perceptual change that exists while flying may not affect the subjective taste experience of lay people. Ultimately, current knowledge regarding flavor perception onboard airplanes is inadequate.

**Data availability**

**Underlying data**


This project contains the following underlying data:

- Participants data.csv (Descriptive participant data)
- Questionnaire data.csv (Raw data from questionnaires).
  Each column is titled in the following manner: [first/second administration]_[item]_[description]. For example, "2_03_bitter" is the second administration of item 3 "bitterness".

**Extended data**


This project contains the following extended data:

- Questionnaire.pdf (The adapted questionnaire used in the study)
- STROBE_checklist.docx (Completed STROBE checklist)

Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public domain dedication).

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**References**


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