

THE ROLE OF 1,1,6-TRIMETHYL-1,2-DIHYDRONAPHTHALENE (TDN) IN INFLUENCING THE
PERCEPTION AND RECOGNITION OF CHARDONNAY AND RIESLING

A Thesis

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by

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ABSTRACT

This study investigates the influence of 1,1,6-Trimethyl-1,2-Dihydronaphthalene (TDN) on the sensory perception of Chardonnay, focusing on whether TDN alone can lead to a misidentification of Chardonnay as Riesling. By exploring the distinctive olfactory contribution of TDN, typically identified in aged Riesling wines, this research examines its effect when introduced into Chardonnay. Using an automated system, sniff olfactometer which can deliver precise dosages of TDN to the headspace of wine samples with controlled timing. This setup allows for precise measurement of recognition probabilities and dose-response relationships, enhancing our understanding of how TDN's presence influences the perceived organoleptic profile of Chardonnay compared to Riesling under similar vintner and vintage conditions.

BIOGRAPHICAL SKETCH

Hanfei Liu is currently pursuing a Master of Food Science with a concentration in sensory science at the Acree Lab. She completed her undergraduate studies in nutrition and food science, with a minor in nutrition communication and education, at the University of Alberta. Hanfei's interest in sensory science was sparked by observing cross-cultural differences in food preferences within her experience of studying in three countries. This experience motivated her to explore how sensory evaluation can be leveraged to better understand food preferences and flavor perceptions, linking closely with nutritional aspects. Additionally, Hanfei is passionate about processed foods, striving to understand how sensory properties of food products affect health and nutritional intake.

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CHAPTER 1

INTRODUCTION

1.1 Role of Smell and Taste in Flavor Perception

The relationship between smell and taste fundamentally shapes the complex sensation of flavor, largely influenced by volatile compounds that activate olfactory receptors. As described by Lawless and Heymann (2010), when food is consumed, aroma compounds are transported through the back of the nasal cavity. This process, enhanced by swallowing, results in what is known as retronasal smell (Spence 2015). The interplay between retronasal olfaction and gustatory cues can lead to congruent or incongruent flavor perceptions, significantly extending beyond the basic five tastes. Research, including that by Murphy and Cain (1980), highlights that odor-taste mixtures can synergistically stimulate both olfactory and taste systems, enhancing overall flavor perception. However, the dynamics of these sensory interactions and their impact on flavor perception offer ample scope for further investigation.

In our laboratory, we delve deeper than the superficial interactions between sensory perception and food by utilizing the Sniff Olfactometer (SO) to examine how individuals respond to mixed odorants. Our research aims to unravel the cognitive processes and behavioral responses associated with specific odorants. We are particularly interested in the role of prior stimulation on odor recognition near threshold levels, employing a Bayesian model to enhance our understanding of human odor perception. In this Bayesian brain framework, every perceptual decision integrates preexisting beliefs with new evidence (Ophelia Deroy, Sofia Rappe, 2022). Through Bayesian analysis, this integration of prior knowledge and new data helps form a posterior distribution used to make informed predictions and decisions, enriching our comprehension of sensory science in a real-world context.

1.2 TDN in Riesling

1,1,6-Trimethyl-1,2-dihydronaphthalene (TDN) is a significant contributor to the distinctive aroma profile of aged Riesling wines, commonly associated with "kerosene" or "petrol" notes (Sacks et al., 2012). TDN, a grape-derived C₁₃ norisoprenoid, does not originally exist in fresh grape berries or juice but develops through the hydrolysis of glycosylated precursors during the processes of fermentation and aging (Sacks et al., 2012). The formation of TDN is influenced by various factors, including the strain of yeast used in fermentation and environmental conditions such as the climate and the amount of sunlight exposure the grape clusters receive prior to veraison (Sacks et al., 2012).

As Riesling wines age, the concentration of TDN can increase significantly, and this compound is noted for its stability during bottle aging (Sacks et al., 2012). It has been reported that TDN levels can reach up to 42 µg/L in Riesling wines aged for ten years and approximately 200 µg/L in wines that have undergone accelerated aging, which are levels well above the sensory threshold of 20 µg/L for detecting the characteristic TDN aroma (Sacks et al., 2012).

1.3 Sniff Olfactometer (SO)

In our laboratory, the Sniff Olfactometer (SO) is a pivotal tool for studying how humans perceive odors, particularly in mixtures. This instrument allows for precise control over the delivery of odorant mixtures to the subjects, facilitating detailed studies on the cognitive and behavioral responses to different olfactory stimuli. Our research aims to dissect the underlying mechanisms of how people respond to specific odorants and their mixtures under various conditions. One area of focus is the effect of prior stimulation on odor recognition, particularly when odorants are presented near their threshold levels. We employ a Bayesian model to better

understand this process, integrating preexisting internal beliefs with new sensory data. This Bayesian approach, as described by Ophelia Deroy and Sofia Rappe (2022), uses prior knowledge about the parameters of a statistical model and combines it with incoming data to form a posterior distribution. This model then informs further predictions or decisions, enhancing our understanding of human olfactory perception and its integration with cognitive processes. Through the use of the SO, we can more effectively explore the psychophysical functions of human perception, leading to deeper insights into how odorants influence cognitive and sensory experiences.

1.4 Objective

The primary objective of this research is to investigate the effect of 1,1,6-Trimethyl-1,2-Dihydronaphthalene (TDN) on the sensory perception of Chardonnay and assess whether its presence can lead to the misidentification of Chardonnay as Riesling. This study aims to explore the sensory impact of TDN, a key aroma compound of aged Riesling, when introduced into Chardonnay. By comparing the organoleptic profiles of Chardonnay and Riesling from the same vintner and vintage, this research seeks to determine if TDN alone can cause tasters to confuse Chardonnay with Riesling. The goal is to understand how TDN affects flavor perception and wine identification across different cultural contexts, thereby potentially influencing global market preferences and winemaking practices. This study will use a double-blind experimental design to isolate the influence of TDN and record the threshold concentrations necessary for its perceptual dominance in Chardonnay.

CHAPTER 2

MATERIALS AND METHODS

2.1 Materials

In our research, we used a Sniff Olfactometer to administer brief bursts (around 1 seconds) of headspace from a solution of 50 ml held within a 250 ml Teflon bottle, which we call the "sniff bottle." To create a set of three varied stimulus concentrations, we arranged three sniff bottles on a sniff block (as depicted in Figure 1). Each bottle was methodically moved through every position on the block and received four puffs in one session, resulting in 12 repetitions for each concentration level.

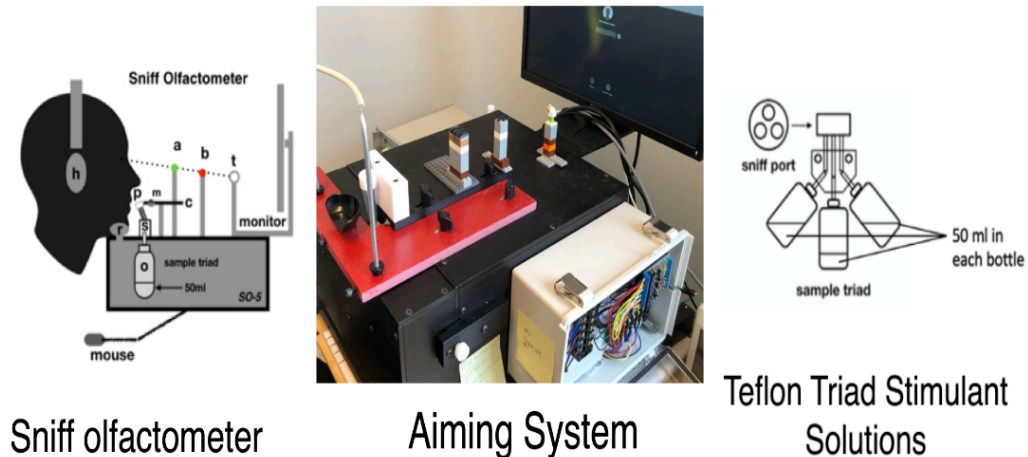


Figure 1: Layout of the Sniff Olfactometer setup showing the aiming system and Teflon Triad bottles arranged in a sniff port from left to right.

Each trial involved administering a single puff of odorant headspace, after which participants had enough time to respond by clicking a mouse. The synchronization of visual cues, odorant puffs, and response timing was controlled using a PsychoPy script created by Peirce et al. (2007, 2019). To ensure precise head positioning and consistent proximity between the

participant's nose and the sniff port, the olfactometer was fitted with an aiming system that utilized a three-point visual alignment mechanism.

Participants were directed to concentrate on the monitor and follow the prompts "aim," "inhale," and "break" as shown in Figure 2.



Figure 2: Timing and flow for each triad in the study.

The primary software used to control the SO was PsychoPy. This platform supported the experiments by setting up experimental parameters, which involved displaying instructions and scales for panelists to assess and rate their sensory perceptions, and allowed them to self-administer the stimuli using a mouse click. PsychoPy also handled the data recording as panelists performed experimental tasks, capturing various measurable details that could be tailored to the study’s requirements. The data from the three different tests were extracted from PsychoPy and subjected to analysis with statistical software, including R and Mathematica.

Table 1: Materials used in the experiment.

Item	Sourced From
1,1,6-Trimethyl-1,2-Dihydronaphthalene (TDN)	Neta Scientific
Sans Oak Chardonnay 2022	Red Tail Ridge, Finger Lake
Riesling 2016	Red Tail Ridge, Finger Lake
Polyethylene Glycol 400 (PEG 400) CAS Registry No. 9002-88-4	JT Baker®, Avantor Performance Materials, Inc

2.2 Participants

Four participants, comprising two males and two females aged between 22 and 28 years, took part in this experiment. These subjects were international students from varied academic disciplines, including human ecology, hospitality, and food science. None of the participants had previous experience with similar experiments. Notably, one participant was a smoker. All participants were selected based on their experience with drinking white wine, with a minimum consumption frequency of two drinks per week.

On the day of the experiment, participants were instructed to abstain from wearing perfume. They were also advised to avoid consuming flavored foods and beverages, as well as smoking, an hour prior to the experiment.

To minimize interruptions and potential cognitive biases, interactions between researchers and participants were deliberately restricted throughout the experiment. Oral communication was confined to delivering instructions on operating the Sniff Olfactometer and addressing participant inquiries during the testing process. All participants completed the experiment, and there were no dropouts during the testing phase.

Recruitment of subjects was facilitated via social media platforms, and the Institutional Review Board (IRB) at Cornell University granted approval for the study involving human participants. The IRB oversight ensured adherence to ethical standards and compliance with regulations aimed at protecting the welfare of human research subjects.

2.3 Sample Preparation

Table 2: Table of the TDN sample concentrations used in 2 parts of experiment.

Part 1	ppb	117.5	263	588.8	1174.9	2951.2	6606.9
	μm	0.68	1.53	3.42	6.82	17.13	38.35

Part 2	ppb	1	10	501.19	1584.89	6309.57	31622.78
	µm	0	0.11	2.91	9.20	36.63	183.56

In the experiment, we utilized TDN (1,1,6-Trimethyl-1,2-Dihydronaphthalene) as the odorant due to its distinctive attributes that resemble the aroma profile commonly associated with aged wines (Sacks et al., 2012). This selection is based on TDN's capability to provide a consistent and identifiable scent that greatly aids in assessing sensory perception among subjects, particularly its impact on the recognition of wine varieties.

For the preparation of our TDN solutions, we began by creating a concentrated stock solution at 1000 ppm. This concentration was achieved by dissolving 0.1g of TDN in 100ml of polyethylene glycol (PEG), chosen for its chemical inertness and minimal odor interference. This stock solution was subsequently diluted using PEG to prepare various testing concentrations that are commonly encountered in sensory analysis of wines.

Once the stock solution was prepared, we proceeded to dilute it further into more refined concentrations using Chardonnay. This method was intended to mimic realistic conditions under which wine tasters might encounter TDN in actual wine tasting scenarios. These dilutions aimed to explore a range of concentrations from very subtle to more pronounced levels, ensuring that the odorant's presence could be assessed across a spectrum of detectability.

To ensure the solutions were devoid of any residual solvent odors that could skew the results, the initial PEG solution was treated to remove any impurities. The samples were mixed thoroughly by mixer and allowed to stabilize overnight, guaranteeing uniform distribution of TDN within the Chardonnay for accurate sensory evaluation.

2.4 Experimental Set Up and Breakdown

The test questions, cues, and instructions were displayed on a monitor that the panelists were instructed to sit in front of. The monitor and table heights were changed at the beginning of each session to make the panelists' surroundings more comfortable. There was also a chin rest available for the panelists to rest their heads on. In order to prevent aural distractions and potential indications from the SO, the panelists were next advised to wear noise-cancelling headphones and to position their noses just above the puff. Panelists answered questions by using a mouse to click through to the next section of the test when they were ready.

2.5 Panelists

Each panelist reported consuming white wine at least two drinks a week, indicating a habitual familiarity with this beverage type. Although they all possessed basic knowledge of wine, which provided a foundational understanding of sensory attributes typical in white wines, their individual experiences and perceptions added depth to the study's findings. Notably, one of the panelists is a smoker, a factor considered in the analysis due to its potential to influence olfactory sensitivity and overall sensory perception.

2.5.1 Training Session

Table 3. Summary of Training Sessions.

Part	Sample	Training Description
Part 1	TDN (38.25 μ m) + Chardonnay	Petrol
Part 2	Pure Riesling	Riesling
	Pure Chardonnay	Not Riesling

This table organizes the training components clearly, showing the flow from teaching about the impact of TDN in Chardonnay to recognizing and differentiating Riesling and Chardonnay.

2.6 Individual Test Sessions

During the test sessions, panelists were presented with six solutions of varying concentrations. Initially, they were provided three specific TDN concentrations and asked to respond accordingly. Subsequently, another set of concentrations was introduced for replication. Thus, in a single session, panelists had the chance to evaluate six different concentrations. The solutions were presented in a non-sequential order, as part of a triad, demonstrating that the order of presentation varied (Ni et al., 2022). The samples were presented by the lowest, third, fifth level of TDN concentrations, as showed in Figure 3. This aim to increase the distance of each sample that presents to panelist in each trail (Ni et al., 2022). Twelve times of each concentration presented to each panelist in random order.

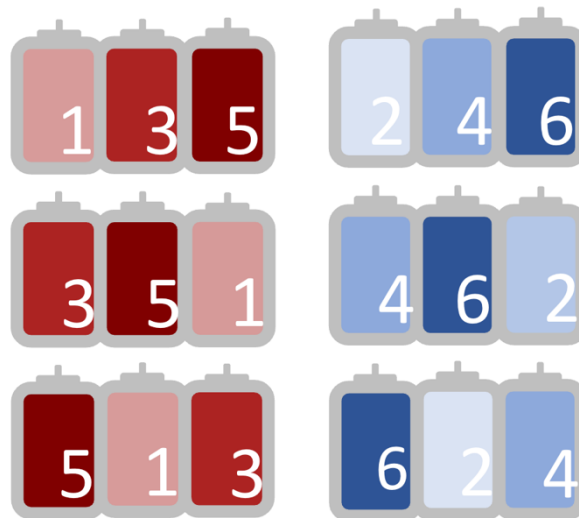


Figure 3: Visualization of the solutions in the two triad sets.

During the experiment, after each randomized trial of the three concentrations (a set), participants were asked specific questions to assess their sensory evaluation to the aromas. In Part 1, following the random presentation of Chardonnay samples infused with varying concentrations of TDN, "Did you smell petrol?" This query aimed to determine individual's TDN threshold in Chardonnay, with options for a simple "Yes" or "No" response. In Part 2 of the study, after random exposure to samples of TDN in Chardonnay, the question posed to participants was, "Did you smell Riesling?" This was designed to test the level that would cause misidentification of Chardonnay with TDN and Riesling.

CHAPTER 3

RESULTS

3.1 Dose-response Curve

A sensory system's input-output function is captured throughout a dynamic range by the dose-response curve (Lawless and Heymann 2010). A semi-hyperbolic pattern was shown by plotting the perceived intensity of a particular concentration using the log concentration solutions. According to Lawless et al. (2010), this connection exhibited the same pattern as a typical dose-response curve for pharmacological stimuli. The threshold range is the initial inflection point at which the curve begins to rise steeply. The panelists regarded the concentrations to be at a high level and saturated when they were unable to distinguish between the intensities, as shown by the second flat zone of the S curve, which represents a maximum response.

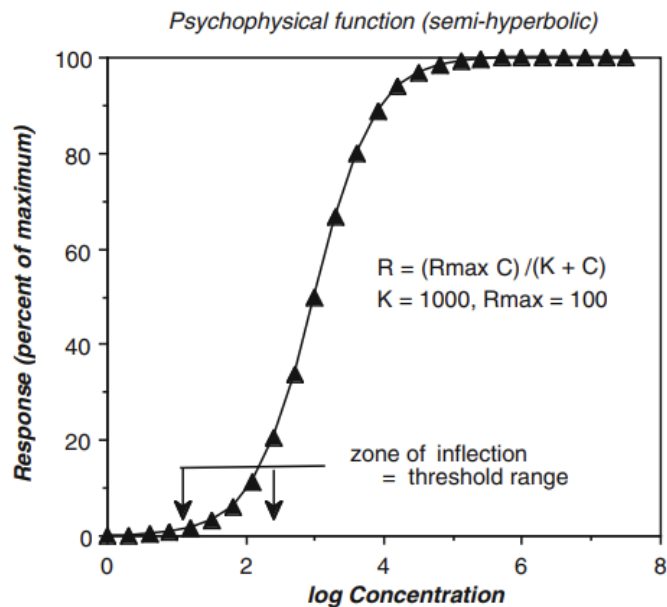


Figure 4: Common semi-hyperbolic relationship of dose-response curves for chemical stimuli (Lawless and Heymann 2010).

3.2 Results of Experiments

The data depicted in the figures illustrate a semi-hyperbolic dose-response relationship typical of sensory and pharmacological studies, as described by Lawless and Heymann (2010). The graphs demonstrate how perceived intensity of TDN in Chardonnay increases with the logarithm of its concentration. The threshold range, where the response curve begins to rise steeply, indicates the minimum concentration at which TDN becomes noticeable to the panelists. We chose the data point where the probability at 0.5 (panelist had 50% chance to recognize TDN) as individual's TDN recognition threshold in Chardonnay (Lawless & Heymann, 2010).

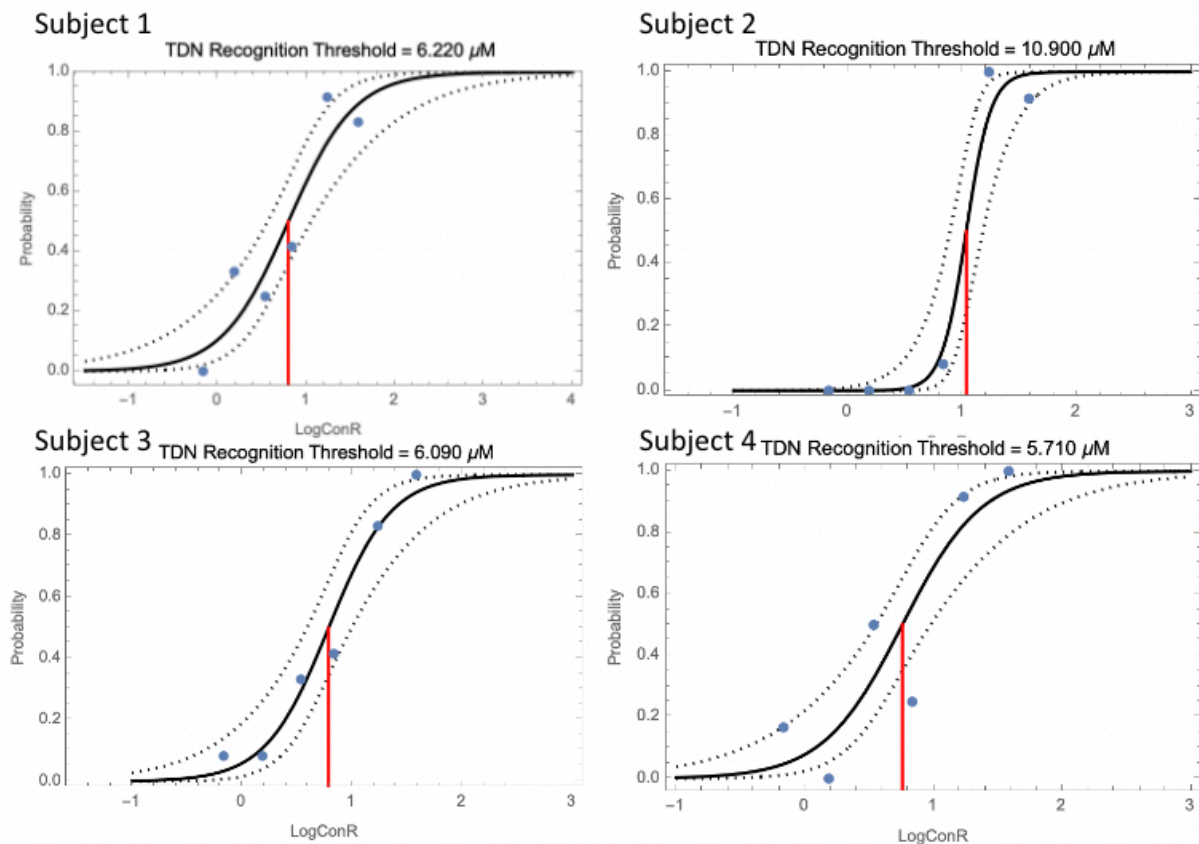


Figure 5: Individual dose-response curves for the TDN Recognition Threshold in Chardonnay

This is shown in Figure 5, where the zone of inflection is marked. Figure 6 presents individual dose-response curves for each panelist, pinpointing the specific TDN concentration thresholds. These thresholds vary among subjects, ranging from 5.710 μM to 10.900 μM , suggesting individual differences in sensitivity to TDN.

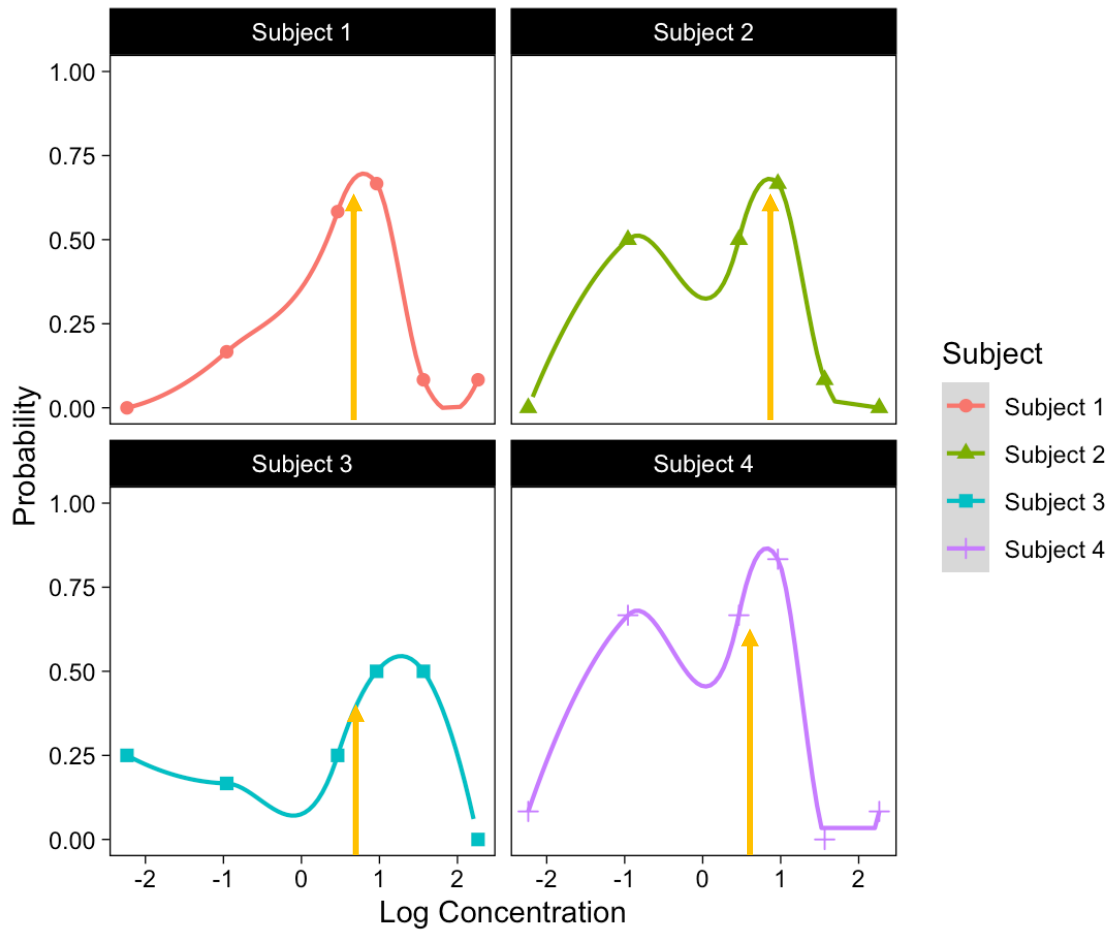


Figure 6: Individual responses of identification of Riesling, tested by TDN in Chardonnay).

Figure 6 presents the individual response curves of four subjects identifying Riesling when tested with varying concentrations of TDN in Chardonnay. Each curve illustrates the probability of a subject mistaking Chardonnay for Riesling at different TDN concentrations, marked on a

logarithmic scale. The highest data point on each curve, indicated by a yellow arrow, represents the individual threshold at which the subject most frequently misidentified Chardonnay as Riesling due to the influence of TDN.

CHAPTER 4

DISCUSSION AND FUTURE WORK

4.1 Data Discussion

The results from our study demonstrate that the addition of a single odor, specifically 1,1,6-Trimethyl-1,2-Dihydronaphthalene (TDN), to Chardonnay can modulate sensory perception significantly enough to cause misidentification as Riesling. This finding is aligned with the psychophysical model where the highest identification rates of Riesling occurred at TDN concentrations ranging from 7.9-15.8 μM in Chardonnay. It was particularly notable that individuals' peak identification rates closely matched their personal TDN recognition thresholds. Furthermore, an intriguing phenomenon observed was the increase in Riesling identification rates even below these recognition thresholds, suggesting the presence of a "silent note"—a sensory perception not overtly recognized but still influential.

This modulation of sensory perception by a single odorant can be crucial in the food and beverage industry, particularly in products with complex aroma profiles like wines. The ability to control or modify these perceptions can allow producers to craft desired sensory experiences more precisely, potentially leading to more distinct and marketable products.

4.2 Future Directions

Looking forward, the implications of this research could extend well beyond wine. The methodology of measuring and modulating single odors in beverages could be applied to a range of alcoholic products where the aroma significantly influences consumer preferences and product identity. This could lead to innovations in how beverages are blended, for example, in the craft brewing industry or in the production of flavored spirits.

Further research could explore the integration of these sensory manipulation techniques with emerging technologies such as artificial intelligence to optimize flavor profiles based on consumer data and preferences. Additionally, expanding these studies to include a broader range of odorants and their interactions could provide deeper insights into the sensory architecture of complex beverages and how they can be tailored to meet specific market demands or consumer trends.

This approach not only opens new avenues for product development but also contributes to a more nuanced understanding of sensory perception and its role in consumer behavior within the food industry.

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