Taste It!

7-Day Exposure to a Protein-Enriched Milk Drink Increases Its Smell, Taste, and Flavor Familiarity and Facilitates Acquisition of Taste Familiarity of a Novel Protein Drink

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Highlights

- 7-day repeated exposure (RE) of a protein-enriched drink in 100 adults
- Separate investigation of smell, taste, and flavor
- RE increases familiarity of smell, taste, and especially flavor
- Changes in familiarity correlate significantly with changes in hedonic rating
- Acquired taste familiarity transfers to a similar, yet novel drink

Abstract

Novel and reformulated food, in particular protein-enhanced drinks, provide an important strategy to promote healthy eating. Despite their availability, protein-enriched foods are not widely accepted, likely owing to their unexpected "taste". Those expectations change with experience and exposure may improve product acceptance. However, the sensory drivers of this phenomenon are unknown. In this randomised, controlled, multi-center trial with pre and post intervention measurements, 100 healthy adult participants consumed either a novel protein-enriched milk drink (PD) or a conventional milk drink (CD) for seven days. Participants evaluated familiarity and hedonic value of the taste, smell, and flavor of different milk drinks including the intervention drinks in the laboratory before and after a seven day exposure. A novel protein-enhanced drink was evaluated after intervention only. Exposure to PD increased familiarity of its smell, taste, and especially flavor. The perception of the other non-exposed drinks was unchanged. PD exposure also led to increased taste familiarity of a novel protein drink suggesting that the "acquired taste" transfers to other protein drinks. While PD hedonic ratings were unaffected by exposure, increased familiarity was positively associated with hedonic ratings for all three sensory modalities smell, taste, and flavor. No changes in the perception of any drink were observed in the group consuming the CD. The transfer of the acquired taste familiarity to a novel drink after 7-days of exposure to an unfamiliar protein-enriched drink indicates that exposure may increase acceptance of similar drinks.

Keywords: smell, taste, flavor, repeated exposure, acceptance, familiarity acquisition, generalization

1 Introduction

Nutrition represents a critical determinant of health. As such, there is an increased effort in developing strategies to improve nutrition on a population scale as a proxy to improve health. These efforts have increased especially in the last decades due to the increased rates of chronic diseases such as obesity (WHO, 2017) but also due to an increase in the ageing population. Strategies to improve nutrition include introducing new functional ingredients or foods that address specific nutrition requirements (Federici et al., 2019; Jaenke et al., 2017) such as protein-enriched foods (van Til et al., 2015). While in theory these foods may improve nutrition, for example by providing the needed protein, several factors including the "novelty", the sensory profile, and individual differences in expectations and motivations associated with such foods as well as socio-demographic factors may negatively impact acceptance in the general population (Baker et al., 2022; Frewer et al., 2003; van der Zanden et al., 2015).

Nutrition labelling, especially using front of pack labels, has been a relatively successful strategy to promote healthy eating (Anastasiou et al., 2019; Campos et al., 2011). Labels attract attention to the nutrition information and can improve food choices (Bialkova et al., 2014; Rramani et al., 2020; van Herpen & van Trijp, 2011). Nutrition labels or claims also increase inferred healthiness and may even elicit negative taste expectations ("unhealthy-tasty" intuition) that discourage individuals to approach or consume healthy foods (Liem et al., 2012; Raghunathan et al., 2006; Schouteten et al., 2015). Such detrimental effects need to be considered especially for novel functional foods, with which individuals have no actual consumption experience but rely solely on beliefs and expectations, often based on nutrition claims provided on the packaging of these foods. Exposing individuals to novel foods may thus lead to an update of beliefs and expectations and increase familiarity. Therefore, understanding the effects of repeated exposure on the acceptance and perceived pleasantness of foods is important.

Repeated exposure can increase the acceptance and liking of novel or initially disliked foods in children (see Appleton et al., 2018, Spill et al., 2019 for reviews) - already for infants and in early childhood (see Anzman-Frasca et al., 2018; Spill et al., 2019; Ventura & Worobey, 2013 for reviews) - and adults (Appleton et al., 2018; Ballard et al., 2017; Eertmans et al., 2001; Pliner, 1982; Rozin & Schiller, 1980). Exposure can also decrease food neophobia (Cooke, 2007), consistent with the "mere exposure effect", according to which attitudes towards the exposed stimuli change (Zajonc, 1968). It would thus be plausible to assume that exposed foods become more pleasant as well, given that pleasantness is an important determinant of acceptance (Baker et al., 2022; Onwezen et al., 2021). However, novelty seems to influence this relationship as exposure to familiar foods could increase monotony and boredom. It was shown that the more a drink is perceived as unfamiliar, the more its pleasantness increases (Sulmont-Rossé et al., 2008). Differences in novelty of exposed foods may hence have contributed to previous studies reporting no effects or even reduction of pleasantness of exposed foods (Essed et al., 2006; Hetherington et al., 2002; Liem & Graaf, 2004; Zandstra et al., 2000).

Additionally, these previous studies only assessed the effect of exposure and familiarity on preference and perceived pleasantness upon or after consumption and did not assess different modalities separately. Food acceptance and preference, though, relate to several modalities and attributes since eating is a multisensory experience. As such, to understand the mechanism of repeated exposure on acceptance, it is important to assess also sensory experiences, such as taste, smell, and flavor, associated with the exposed food. Taste is the chemosensory percept mediated by taste sensors in the mouth. It relates to the basic qualities sweet, sour, salty, bitter, and umami. Smell is the chemosensory percept mediated by olfactory receptors in the nose. Flavor perception results from the integration of smell and taste and is typically experienced during food consumption.

Studies on repeated exposure effects on smell support a mere exposure effect, at least for neutral and pleasant odors but not for malodors (Delplanque et al., 2008; Delplanque et al., 2015). In the context of food, repeated exposure enhances the pleasantness of the food´s odor (Anguah et al., 2017; Fondberg et al., 2021). Furthermore, it has been suggested that familiarity affects hedonic judgements, such that familiar smells are liked more than unfamiliar ones (Distel et al., 1999; Sulmont et al., 2002), and familiar taste-smell combinations are judged as more pleasant than less familiar combinations (Amsellem & Ohla, 2016).

Previous attempts to assess exposure effects on taste were confounded by the common confusion of taste with flavor or retronasal smell. For example, exposure to a soup with no added salt led to increased pleasantness but also increased perceived saltiness (Methven et al., 2012). Similarly, taste pleasantness of a bitter-sweet beverage was enhanced with exposure (Stein et al., 2003). While the authors concluded that taste pleasantness was enhanced, it cannot be excluded that participants evaluated the overall flavor of the food rather than its taste, which requires an analytical perspective that typically only trained panellists exhibit. To avoid confusion of taste with flavor / retronasal smell, Anguah et al. (2017) asked participants to explicitly rate both taste and flavor of products and found exposure effects on both. While explicit instructions can help take an analytical stance (Le Berre et al., 2008) and evaluate taste more independently of smell, influences of ortho- and retronasal smell on taste ratings could not be unequivocally excluded. Rating of a food based on its consumption will naturally conflate the different sensory experiences of taste and retronasal smell, the latter of which is typically even mislocalized to the mouth (Spence, 2016). It is therefore crucial to minimise olfactory experiences during consumption, for example by wearing a tight nose clip during sampling and rating.

Overall, previous studies assessed the effect of exposure and familiarity on preference and perceived flavor pleasantness but did not consider the impact of repeated exposure on individual sensory experiences associated with food. For better acceptance outcomes of reformulated foods, manufacturers often have to trade-off between making a food product “healthier” but also acceptable in terms of sensory qualities such as taste, smell, and texture. Understanding which modality is most susceptible to exposure may thus help minimise the trade-off between perceived “healthiness” and perceived pleasantness. In addition, previous studies did not assess whether exposure effects are generalized to similar stimuli or products. However, this is of special interest in a nutritional context, as acceptance of one healthy food may increase simultaneous acceptance of similar healthy food items.

Here, we investigated which perceived food qualities change as a result of repeated exposure. One hundred participants consumed either an unfamiliar protein-enriched milk-mixed drink or a familiar milk-mixed drink during seven days and rated taste, smell, and flavor before and after exposure. We chose an intervention phase of seven days to accommodate the findings that five to fifteen exposures were sufficient to enhance the preference of a novel food in children (Birch et al., 1987; Birch & Marlin, 1982; Liem & Graaf, 2004; Sullivan & Birch, 1990), while young adults exhibited increased boredom over a 12-day exposure (Essed et al., 2006). In addition, participants rated a novel protein-enriched milk-mixed drink after being exposed for seven days to one of the previous drinks. We hypothesized that repeated exposure to the drink would increase familiarity and perceived pleasantness. We expected this effect to be more pronounced for flavor than for taste and smell (modality effect), as naïve participants are used to evaluating flavor in everyday life. Additionally, we expected that the effect of repeated exposure on pleasantness would be stronger for unfamiliar drinks. Considering the reported relation between familiarity and pleasantness, we expected that a change in familiarity will relate positively to a change in perceived pleasantness. Further, we hypothesized that exposure to an unfamiliar protein-enriched drink would increase familiarity and perceived pleasantness of a novel but similar protein-enriched drink (generalization effect).

2 Methods

2.1 Participants

The study was approved by the local ethics committee of the University of Bonn, Medical Center (No. 214/20). The study protocol conformed to the declaration of Helsinki. Participation in the study was voluntary, participants gave written informed consent, and were paid €40. Based on a prior sample size calculation using G*Power (Faul et al., 2009) (see Supplementary Material 11 for details), we recruited 106 healthy volunteers, half of which were each tested at the Fraunhofer Institute for Process Engineering and Packaging IVV in Freising and the BonnEconLab in Bonn. In Bonn, participants were recruited via the hroot database (Bock et al., 2014) of the BonnEconLab. Data from six subjects were excluded because they did not complete all sessions. Exclusion criteria were: being underweight or overweight/obesity (BMI < 17.5 or > 30 kg/m^2, respectively), having neurological, psychiatric, or psychological conditions, having food allergies or intolerances, diabetes, or any condition known to affect taste, smell, and flavor perception and metabolism. To ensure familiarity with milk drinks and support compliance, participants were to have lived in Germany and/or Austria for at least five years and to express liking milk drinks. Participants had to be fluent in German to understand the rating scales and questionnaires. Participants were asked not to eat 2 hours before each lab session (fasted hours before experiment: M = 5.46, SD = 4.43; perceived hunger [scale from 1 to 9]: M = 5.10, SD = 2.02).

2.2 Stimuli

We used five chocolate-flavored milk drinks and prepared them based on ingredients available in the German market:

- Conventional drink (CD): 13.5 g Nesquik powder (Nestlé Kaffee & Schokoladen GmbH, Frankfurt am Main, Germany) dissolved in 200 mL 3.5%-fat milk
- Protein drink (PD): CD with 14 g Nutri Shape and Shake natural flavored protein powder (Nutrition-Plus Germany e.K., Grafschaft, Germany)
- Additional drink I (ADI): 13.5 g light Nesquik powder (Nestlé Kaffee & Schokoladen GmbH, Frankfurt / Main, Germany) dissolved in 200 mL 0.1%-fat milk
- Additional drink II (ADII): Arla chocolate-flavored protein drink (Arla Foods Deutschland, Düsseldorf, Germany)
- Novel drink (ND): 40 g chocolate Huel powder (Huel GmbH, Berlin, Germany) dissolved in 200 mL 0.1%-fat milk.

We used the CD and PD to investigate repeated exposure effects. Whereas CD was a well-established drink in the German market, PD was unfamiliar (see also Section 3.1). The ADs served as control drinks. The ND served to investigate assimilation or transfer effects, as it was similar to the PD in terms of protein content (PD: 9.7, ND: 9.2 versus CD: 3.8, ADI: 4.2, ADII: 5.6 [g/100mL]) and texture.

Drinks were presented in paper cups labelled with unique three–digit codes. For smell evaluation, 50 mL samples were provided in open cups, which were to be brought close to the nose while breathing normally. For taste evaluation, 50 mL samples were provided in closed cups with a straw. Participants tasted the samples while wearing a nose clip and they were to “sip and spit” without swallowing to minimise ortho- and retronasal smell. For flavor evaluation, 100 mL samples were provided in cups covered with a lid with a spout. Participants were to sip, twirl the bolus in their mouth for a few seconds and then swallow. For taste and flavor evaluation, they rinsed their mouth with water between samples.

2.3 Study design

This randomised controlled trial with pre and post intervention measurements comprised three phases (see Figure 1): Phase I (baseline, pre intervention) and Phase III (follow-up, post intervention) took place in the laboratory eight days apart. Phase II (intervention) was carried out at home during the intervening seven days. Participants were randomly assigned to either the protein (PG) or the conventional group (CG).

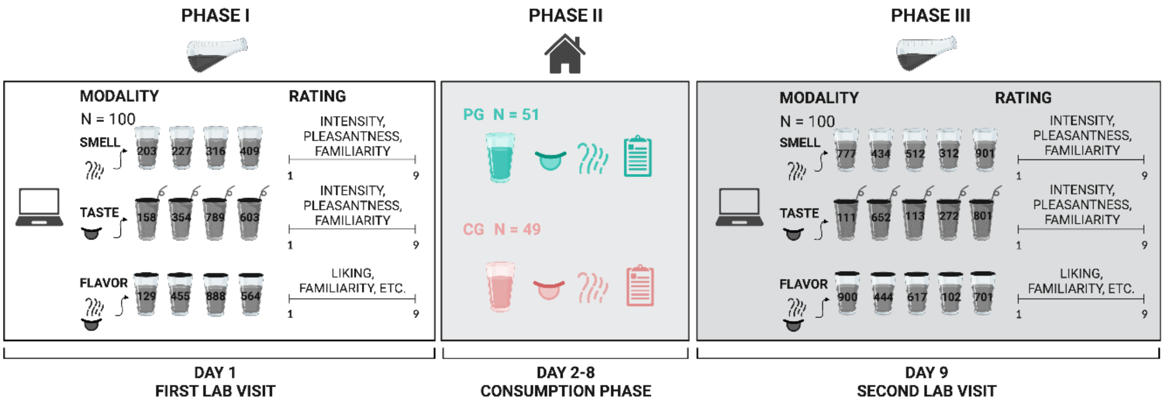

Figure 1. Overview of study design. The study consisted of 3 phases. In phase I, participants evaluated the smell, taste, and flavor of four different milk-mixed drinks: a conventional drink (CD), a protein drink (PD), an additional drink I (ADI), and an additional drink II (ADII). In Phase II, participants were randomly divided into two groups: one consumed CD, the other PD, for seven days. In Phase III, participants then re-evaluated the four drinks plus a novel, protein-rich drink (ND) in the laboratory and filled out additional questionnaires.

Phase I (Day 1): A questionnaire implemented in Qualtrics (Qualtrics, Provo, UT) guided participants through Phase I in the lab. First, participants provided demographic information and baseline ratings for hunger, arousal, valence, and stress on 9-point scales anchored with "not at all" (1) and "very much" (9). They then evaluated the smell, taste, and flavor during sampling of four different milk drinks (PD, AD1, AD2, CD; see Section 2.2). They rated intensity, pleasantness, and familiarity of each drink's smell and taste, and for each drink's flavor the health expectation, familiarity, liking[1], wanting, texture, willingness to buy, and willingness to pay for (see Supplementary Material 9 for the exact wording of the questions). Familiarity ratings for smell, taste, and flavor and pleasantness ratings for smell and taste and liking for flavor were variables of interest; the other variables were exploratory. Smelling, tasting, and sampling for flavor were done in blocks with fixed order (see Figure 1, Phase I). The order of drinks within each sensory modality was randomised.

Phase II (Day 2–8): In Phase II, participants were randomly assigned to either of two groups: participants in CG (N = 49) consumed the CD and participants belonging to PG (N = 51) consumed the PD, 200 ml each day for seven days at their preferred time. Participants were blind as to the assigned group/drink. To decrease variation in the preparation of the drink, participants were supplied with seven packages of powder (each containing the exact amount needed per day), two litres of 3.5 %-fat milk, and instructions on how to prepare and store the drink. To ensure compliance, participants were asked to rate perceived pleasantness, intensity, and ease of consumption on 9-point scales anchored with "not at all" (1) and "very much" (9) daily after consuming the drink (see Supplementary Material 10 for the exact wording of the questions).

Phase III (Day 9): Phase III was similar to Phase I, with the exception that an unfamiliar, novel drink (ND) with a similar protein content as PD was added to the protocol. After evaluation of the five drinks, participants were given a list of the names of the drinks used and asked if they knew or had tried any of

[1] We used different wordings to assess the hedonic evaluation of taste and smell in comparison to flavor to accommodate the lack of a uniformly accepted and comprehensible translation of flavor (see Supplementary Material 9).

the drinks before. In addition, they completed the German version of the Dutch Eating Behavior Questionnaire (DEBQ; Grunert, 1989) as well as the Food Neophobia Scale (FNS; Pliner & Hobden, 1992).

2.4 Statistical analysis

First, we tested for group and session differences in age, BMI, eating styles (DEBQ; Grunert, 1989), neophobia (FNS; Pliner & Hobden, 1992), baseline hunger, arousal, valence, and stress ratings using linear mixed models. We calculated percentages to describe the proportions of participants who knew and who had already tried the different milk-mixed beverages.

To assess the effect of repeated exposure on the different sensory modalities, we estimated linear mixed models with smell, taste, and flavor ratings as dependent variables; time (phase I, phase III), group (PG or CG), and drink (CD, PD, ADI, ADII) were modelled as fixed effects. A random intercept was added per participant to account for interindividual differences in mean ratings. Smell and taste ratings for pleasantness and familiarity as well as flavor ratings for liking were variables of interest; the other variables were exploratory and reported in the Supplementary Material.

To assess whether exposure would enhance the pleasantness of unfamiliar drinks more than the pleasantness of already familiar drinks, we compared-the change in pleasantness for smell and taste as well as liking for flavor for the repeatedly consumed drink (i.e., PD for PG and CD for CG) between the two groups and for each of the three sensory modalities with *t*-tests. For this, we calculated difference scores by subtracting pre-ratings from post-ratings.

To assess which modality was impacted most by repeated exposure, we submitted the change (post minus pre) in pleasantness for smell and taste and liking of flavor and familiarity of the PD in the PG as dependent variables in linear mixed-models with modality (smell, taste, flavor) as fixed effect and an intercept per participant.

To assess whether a change in familiarity was related to a change in pleasantness, we estimated linear mixed models for each sensory modality with the corresponding difference (post – pre) in familiarity as independent and the difference in pleasantness as dependent variables. We added a random intercept per participant and drink and group as covariates.

To examine generalization or transfer effects to the ND, we calculated for each smell, taste, and flavor rating of the ND a linear mixed model with the rating as dependent and group as independent variable. Additionally, we examined the association between familiarity and pleasantness ratings for ND per modality by estimating linear mixed models for each sensory modality with ratings for pleasantness / liking as DV and ratings for familiarity as IV and group as a covariate.

For post-hoc tests, *p*-values were adjusted using Holm-correction and degrees of freedom were approximated using the Kenward-Roger method. To complement null-hypothesis significance testing (NHST), we computed Bayes Factors (BF) by Bayesian linear mixed models using a Cauchy distribution with a default medium prior scale ($r = ½$). In case of three-way interaction, we calculated corresponding BFs by dividing the BF of a model with the three-way interaction by the BF of a model without it. As a robustness check, we varied the prior width parameter from $r = 0$ to $r = 1$ and visually checked resulting BFs. If not otherwise stated, the analysis was considered robust.

Statistical analyses were conducted using R 4.1.0 (R Core Team, 2021). Linear mixed models were performed using lme4 (Bates et al., 2015), lmerTest (Kuznetsova et al., 2017), and emmeans (Lenth, 2022) packages. Bayesian analysis was conducted with the BayesFactor package (Morey & Rouder, 2021). Figures were created using ggplot2 (Wickham, 2016). Statistical tables of linear models are provided in the Supplementary Material.

3 Results

3.1 Participants

The CG consisted of 49 (32 women, 17 men) and the PG of 51 participants (33 female, 18 male). All participants were aged between 18 and 60 years old (M = 26.17, SD = 9.32). No significant differences were observed between groups in age, BMI, eating styles (DEBQ subscores), and Neophobia (see Suppl. Table 1). We also observed no significant differences between groups and phases (I and III) in baseline ratings for hunger, arousal, valence, and stress (see Suppl. Table 2). Whereas the majority of participants knew (CG: 89.8%, PG: 86.3%) and had tried (CG: 89.8%, PG: 78.4%) the CD, the two protein-enriched drinks were unfamiliar to almost all participants (PD: 98% for both the CG and PG; ND: 98% of the CG and 92.2% for the PG).

3.2 Effects of repeated exposure

We predicted that any exposure effect would lead to a significant three-way interaction for time (pre, post) × group (CG, PG) × drink (CD, PD, ADI, ADII). We thus limited our analyses accordingly. The results were similar when age, BMI, DEBQ subscores, neophobia, and location were added as covariates.

3.2.1 Effect of repeated exposure on smell

We found a significant three-way interaction for smell familiarity ($F_{3, 686} = 3.067$, $p = .027$; Figure 2A) and Bayesian analysis supported this finding with anecdotal evidence in favor of H1 (model with three way-interaction between group, time, and drink; $BF_{10} = 1.45$). Post-hoc tests revealed significantly higher familiarity after exposure compared to before only for the PD in the PG ($t_{686} = -3.854$, $p = .001$).

No such interaction was found for intensity ($F_{3, 686} = 0.248$, $p = .863$; Suppl. Figure 1) and pleasantness ($F_{3, 686} = 0.436$, $p = .727$; Figure 2A). The null findings were corroborated by strong evidence in favor of H0 (model without three-way interaction) for pleasantness ($BF_{10} = 0.042$) and intensity ($BF_{10} = 0.035$).

3.2.2 Effect of repeated exposure on taste

Similar to smell, we found a significant three-way interaction for taste familiarity ($F_{3, 686} = 2.705$, $p = .045$; Figure 2B); post-hoc tests revealed significant higher familiarity after exposure compared to before only for the PD in the PG ($t_{686} = -2.861$, $p = .035$). However, we found anecdotal evidence for H0 ($BF_{10} = 0.761$). A robustness check revealed that for a prior scale width from 0.2 to 1.0, the BFs varied between 0.2 and 2. Therefore, using Bayesian statistics we could not establish evidence for one specific hypothesis.

No such interactions were observed for taste intensity ($F_{3, 686} = 1.265$, $p = .285$; Suppl. Figure 1) and taste pleasantness $F_{3, 686} = 1.113$, $p = .343$; Figure 2B). The null findings were supported by moderate evidence in favor of H0 for pleasantness ($BF_{10} = 0.102$) and intensity ($BF_{10} = 0.118$).

3.2.3 Effect of repeated exposure on flavor

In line with smell and taste, we found a significant three-way interaction for flavor familiarity ($F_{3, 686} = 5.079$, $p = .002$; Figure 2C) and strong evidence in favor of H1 ($BF_{10} = 16.93$). Post-hoc tests revealed that the PD in the PG ($t_{686} = -7.992$, $p < .001$) was more familiar after exposure compared to before.

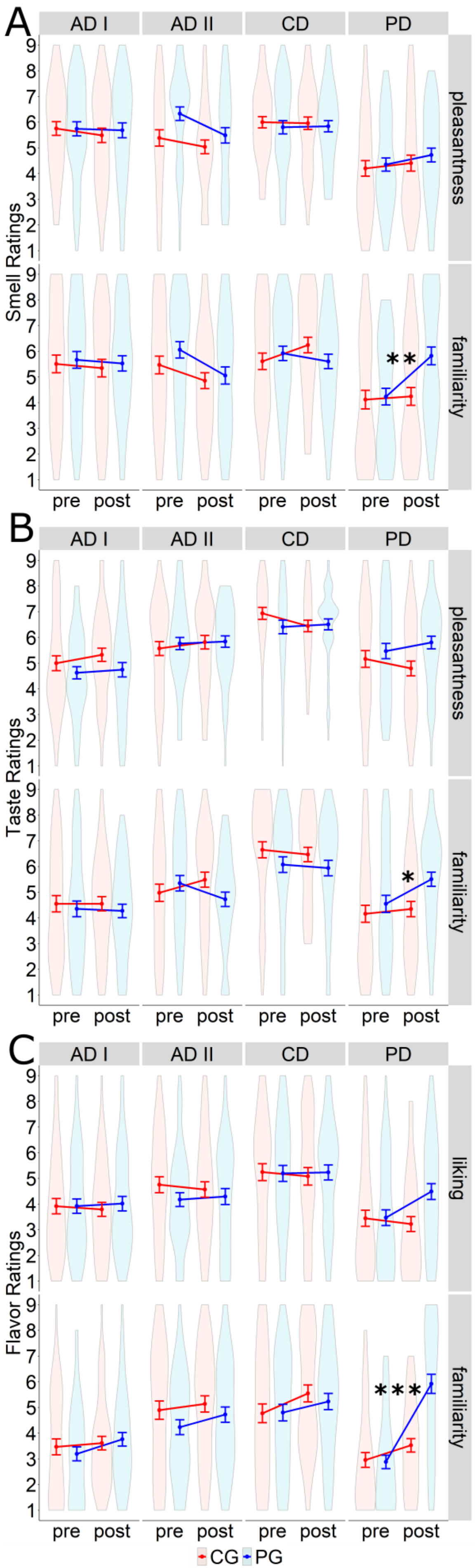

Figure 2. Ratings of smell (A), taste (B), and flavor (C) for different drinks pre and post exposure. Red and blue indicate CG and PG participants, respectively. Violins display the distribution of the data. Dots represent means, solid lines connect means within a group and across time points. Error bars are +/– 1 SEM. CG = Conventional Group; PG = Protein Group. *$p < .05$, ** $p < .01$, ***$p < .001$

No such interactions were found for the other ratings (health expectation: $F_{3, 686} = 0.328$, $p = .805$; wanting: $F_{3, 686} = 0.315$, $p = .815$; liking: $F_{3, 686} = 0.910$, $p = .436$ (Figure 2C); texture: $F_{3, 686} = 0.921$, $p = .430$; willingness to buy: $F_{3, 686} = 0.565$, $p = .638$; willingness to pay: $F_{3, 686} = 0.247$, $p = .863$; Suppl. Figure 2). Bayesian statistics supported those findings with evidence against H1 for health expectation ($BF_{10} = 0.034$), wanting ($BF_{10} = 0.035$), liking ($BF_{10} = 0.079$), texture ($BF_{10} = 0.075$), willingness to buy ($BF_{10} = 0.050$), and willingness to pay ($BF_{10} = 0.028$).

3.3 Influence of familiarity on perceived pleasantness

The change in taste and flavor pleasantness was significantly larger for PD in PG than for CD in CG (taste: $F_{1, 98} = 4.89$, $p = .029$, $BF_{10} = 1.799$; flavor: $F_{1, 98} = 5.60$, $p = .020$, $BF_{10} = 2.449$) indicating that repeated exposure enhanced taste and flavor pleasantness ratings of the unfamiliar PD more than the pleasantness ratings of the familiar CD. However, there was no significant difference for the change in smell pleasantness ($F_{1, 98} = 0.89$, $p = .347$, $BF_{10} = 0.314$).

3.4 Sensory modality effects

Next, we examined whether repeated exposure to PD affected smell, taste, and flavor pleasantness and familiarity differently by comparing the difference ratings (post minus pre exposure; Figure 3). Familiarity changes differed significantly between modalities ($F_{2, 100} = 8.343$, $p < .001$) and this effect was supported by strong evidence for H1 ($BF_{10} = 91.232$). Familiarity changes were significantly higher for flavor compared to smell ($t_{100} = 2.780$, $p = .013$), and taste ($t_{100} = 3.982$, $p < .001$). Smell and taste familiarity changes did not differ significantly ($t_{100} = 1.202$, $p = .232$).

By contrast, pleasantness changes were not significantly different between modalities ($F_{2, 100} = 1.644$, $p = .198$) with moderate evidence in favor of H0 ($BF_{10} = 0.293$).

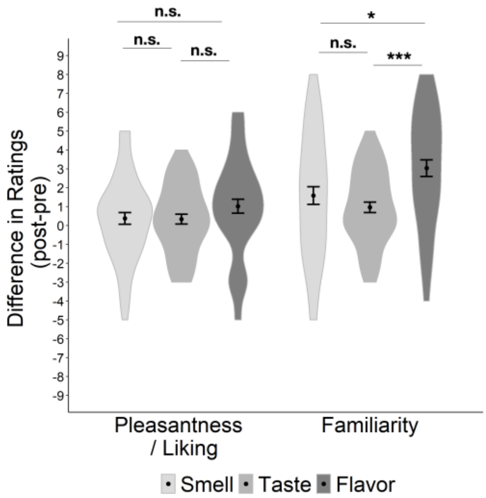

Figure 3. Changes in pleasantness / liking and familiarity for the intervention drink in the intervention group for each modality. Shades of gray indicate sensory modalities. Dots represent means. Error bars are +/– 1 SEM. Violins display the distribution of the data. **p* < .05, ****p* < .001, n.s. = not significant.

3.5 Association between changes in familiarity and pleasantness / liking

Pleasantness / liking changes were significantly associated with changes in familiarity for all sensory modalities: smell ($F_{1, 393} = 264.039$, $p < .001$, $BF_{10} = 1.581e42$), taste ($F_{1, 385} = 220.100$, $p < .001$, $BF_{10} = 4.888e35$), and flavor ($F_{1, 394} = 165.126$, $p < .001$, $BF_{10} = 2.981e27$; Figure 4).

Figure 4. Association between changes (post – pre exposure) in familiarity and pleasantness / liking for each modality. Dots represent individual data points, overlaying data points result in a darker color. The black line represents the linear smooth of individual data points. Gray shaded areas represent the 95% CI. ****p* < 0.001.

3.6 Generalization effects

We hypothesized that perceptual changes due to exposure to the PD could be adopted and transferred to a novel but similar drink that was never sampled before (ND). Accordingly, the CG should evaluate the ND less familiar and less pleasant than the PG. We thus compared ratings of the ND between both the CG and the PG.

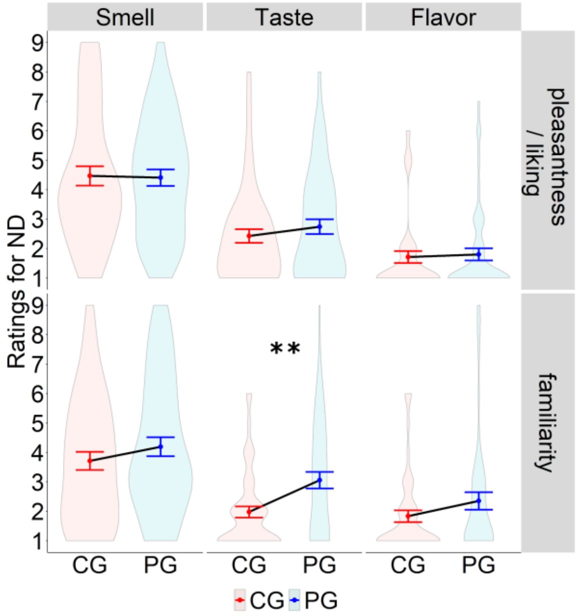

Figure 5. Pleasantness / liking and familiarity ratings for the smell, taste, and flavor for the novel drink (ND) introduced at Phase III. Red indicates participants of the CG and blue of the PG. Error bars are +/– 1 SEM. Black lines connect means and visualize group differences. Violins display the distribution of the data. CG = Conventional Group; PG = Protein Group. ** $p < .01$

3.6.1 Generalization effects on smell

No significant differences were found between groups for smell familiarity ($F_{1, 98} = 1.160$, $p = .284$, $BF_{10} = 0.353$), intensity ($F_{1, 98} = 0.179$, $p = .681$, $BF_{10} = 0.227$), and pleasantness ($F_{1, 98} = 0.018$, $p = .894$, $BF_{10} = 0.213$) of the ND (Figure 5).

3.6.2 Generalization effects on taste

In contrast to smell, the PG rated the taste of the ND as significantly more familiar than the CG ($F_{1, 98} = 10.051$, $p = .002$, $BF_{10} = 16.126$; Figure 5). There were no significant group differences for intensity ($F_{1, 98} = 0.517$, $p = .474$, $BF_{10} = 0.265$) and pleasantness ($F_{1, 98} = 0.859$, $p = .356$, $BF_{10} = 0.309$; Figure 5).

3.6.3 Generalization effects on flavor

No significant group differences were observed for flavor familiarity ($F_{1, 98} = 2.037$, $p = .157$; Figure 5), health expectation ($F_{1, 98} = 0.059$, $p = .809$), wanting ($F_{1, 98} = 1.480$, $p = .227$), liking ($F_{1, 98} = 0.096$, $p = .758$; Figure 5), texture ($F_{1, 98} = 1.246$, $p = .267$), willingness to buy ($F_{1, 98} = 0.031$, $p = .861$), and willingness to pay ($F_{1, 98} = 0.261$, $p = .611$). Bayesian analysis corroborated the null findings with moderate evidence that the groups did not differ in health expectation ($BF_{10} = 0.216$), liking ($BF_{10} = 0.220$), willingness to buy ($BF_{10} = 0.214$), and willingness to pay ($BF_{10} = 0.237$). However, this evidence was only anecdotal for familiarity ($BF_{10} = 0.519$), wanting ($BF_{10} = 0.406$), and texture ($BF_{10} = 0.367$).

3.6.4 Association between familiarity and pleasantness for ND

Ratings for pleasantness / liking of ND were significantly associated with familiarity ratings in all three modalities: smell ($F_{1,97} = 61.937$ $p < .001$, $BF_{10} = 20.158e8$), taste ($F_{1,97} = 34.040$, $p < .001$, $BF_{10} = 14.947e4$), and flavor ($F_{1,97} = 14.776$, $p < .001$, $BF_{10} = 126.768$).

4 Discussion

Epidemiological surveys suggest that as we age, the dietary protein intake may be insufficient to maintain muscle mass (Gaffney-Stomberg et al., 2009; Phillips, 2017). These insufficiencies can be addressed by consuming protein-enriched foods. However, increasing the acceptance of such foods remains challenging owing to the negative taste expectations associated with them. Expectations change with experience and exposure can improve the attitude towards products (Zajonc, 1968), however, the sensory drivers of that change are unknown. To close this gap, we investigated which perceived sensory food quality – smell, taste, or flavor – was modulated by repeated exposure in adults. Our results indicated that repeated exposure for only seven days increased familiarity for the smell, taste, and flavor of an unfamiliar protein-enriched drink. Flavor familiarity increased most, and taste familiarity even transferred to another unfamiliar protein-enriched drink.

Effect of repeated exposure on familiarity

Repeated exposure for only seven days increased familiarity for the smell, taste, and flavor of an unfamiliar protein-enriched drink. Such effects were previously shown for single modalities in different products (e.g., odor: Delplanque et al., 2015, taste: Methven et al., 2012, flavor: Stein et al., 2003; Stolzenbach et al., 2013), thus hindering a direct comparison between studies. By simultaneously investigating all three modalities, we found that familiarity increased most for flavor. Although taste, smell, and flavor are linked, smell and taste are distinct senses whereas flavor is a multisensory percept that includes smell and taste but also other senses such as somatosensation, vision, and sound (Small & Prescott, 2005; Verhagen & Engelen, 2006). In everyday life, consumers typically experience food synergistically – as the sum of the different sensory inputs – and they are seldomly aware of the contributing senses (Rozin, 1982; Spence, 2015; Stevenson, 2014). Smell and taste are intimately intertwined and thus they are difficult to disentangle. Moreover, most of what people describe as “taste” is retronasal smell. This could explain why repeated consumption affects flavor the most, as this was likely the most perceived modality during the intervention, in which we did not control for the different senses like in the pre and post measurement. In contrast, repeated exposure to the CD did not significantly enhance its smell, taste, or flavor familiarity. The CD was notably more familiar to begin with, yet familiarity ratings were in the range of 4 to 7 on a 9-point scale with ample room for further increase. The higher initial familiarity ratings were expected given that participants were selected based on their familiarity with milk-mix drinks and the CD is widely available on the market. Together the results suggest that familiarity is more likely to increase for less familiar drinks than for drinks that are already familiar at medium scale levels. This may indicate a non-linear relationship between exposure and familiarity.

Generalization effect of familiarity

Familiarity is an important factor in the acceptance of food. The term ‘familiarity’, though, has traditionally been used twofold (Köster & Mojet, 2016): on the one hand, familiarity can describe the product at different time points, e.g., when evaluating the PD and CD before and after exposure. On the other hand, familiarity can refer to the similarity to another known product. We show that repeated exposure affects familiarity in both notions: PD exposure not only led to increased smell, taste, and flavor familiarity of the PD, but also to a higher taste familiarity of a similar yet novel drink, ND, compared to CD exposure. The results are consistent with a transfer of an acquired taste: participants acquired the unfamiliar taste of the PD and transferred it to the protein-enhanced ND. The lack of a transfer effect for smell and flavor may indicate the superior role of the sense of taste in the detection of high levels of proteins, which have been associated with umami taste (Winkel et al., 2008; Yan et al., 2021), although umami is an unreliable indicator of protein content, particularly in unrecognized foods (Buckley et al., 2018). Additionally, taste perception is less complex than flavor and may thus facilitate transfer to other protein-enhanced products. Thus, our results indicate that an exposure-derived increased familiarity transfers and generalizes to similar protein-enhanced drinks in adults. Whereas generalization effects of foods were usually shown in infants (Birch et al., 1998; Harris & Mason, 2017; Mennella & Beauchamp, 2002; Spill et al., 2019) the literature in adults is sparse.

Effect of repeated exposure on pleasantness

Familiarity increases acceptance of food likely owing to its strong relationship with pleasantness, which has been shown for smell (Delplanque et al., 2008; Distel et al., 1999; Fondberg et al., 2021; Knaapila et al., 2017; Sulmont et al., 2002), taste-smell combinations (Amsellem & Ohla, 2016), and food products (Borgogno et al., 2015; Karagiannaki et al., 2021). Expanding those previous findings, we found a positive relationship between changes in familiarity and changes in pleasantness in all three sensory modalities: smell, taste, and flavor.

Notably, we observed no exposure-related change in the pleasantness of the PD itself compared to the CD. Further, no generalization effect for pleasantness occurred for ND. Whereas repeated exposure has been previously shown to enhance food liking (Anguah et al., 2017; Appleton et al., 2018; Methven et al., 2012; Pliner, 1982; Stein et al., 2003), other studies reported no such effects (Appleton, 2013; O’Sullivan et al., 2010). This apparent discrepancy is not surprising considering competing theories on the underlying mechanisms, according to which exposure can, on the one hand, enhance familiarity and improve the acceptance and intake of food consistent with a mere exposure effect (Zajonc, 1968). On the other hand, exposure can foster monotony and boredom and, this way, negatively affect pleasantness (Essed et al., 2006; Sulmont-Rossé et al., 2008). Although the PD and ND were rather unfamiliar to our participants, experimental boredom could lead to such effects. Because several factors like individual preferences, product category, or age of participants can influence exposure effects (Essed et al., 2006; Koskinen et al., 2003; Liem & Graaf, 2004; Mattes, 1994; Sulmont-Rossé et al., 2008; Weijzen et al., 2008), it is difficult to predict the magnitude and direction of exposure effects. Interestingly, even if repeated consumption leads to reduced liking, the intake could stay unchanged or even increase (Hetherington et al., 2002; Zandstra et al., 2000) suggesting that liking or pleasantness per se do not necessarily translate to food intake.

In our study, though no direct exposure-related effects, the correlation between changes in familiarity and pleasantness hints to a positive effect of repeated exposure on smell, taste, and flavor pleasantness. Further, we established significant associations between the familiarity and pleasantness of the ND in all three modalities. In addition, repeatedly consuming a novel drink (PD) led to significantly higher differences in taste and flavor pleasantness than repeatedly consuming a familiar drink (CD). That further highlights the role of novelty in repeated exposure effectiveness.

Further effects of repeated exposure

In addition to familiarity and pleasantness, we also assessed other exploratory variables for which we found no exposure effects. Specifically, we found no differences of smell and taste intensity between the repeatedly consumed CD and PD, and the additional drinks ADI and ADII. This is in contrast to a study that reported a reduction in perceived intensity for bitter beverages (Stein et al., 2003). Similarly, we found no effects for health expectation, wanting, texture, willingness to buy, and willingness to pay for. We can only speculate that these factors may only be affected after a longer exposure time. Future studies will have to further explore the effects of exposure on these factors as they have been previously shown to be associated with food decision making (Enax et al., 2015; Enax et al., 2016; Leng et al., 2017; Rangel, 2013).

Limitations

Though we instructed participants to only evaluate the modality in question, we cannot exclude that texture / mouthfeel influenced taste ratings. Additionally, we cannot exclude that differences between CD and PD other than familiarity and protein content may have influenced the observed differences in repeated exposure effects. Given the lack of a uniformly accepted and understood German translation for 'flavor', we modified the question used to assess the hedonic value of smell and taste to accommodate it for the paraphrasing of flavor. This change in wording may have contributed to differential interpretations of the ratings question. Our study only investigated repeated exposure effects in young and middle-aged adults over an intervention period of seven days. Future research should investigate the effects on older people or with different exposure lengths. Finally, we suggest the inclusion of qualitative descriptive analyses of used foods or drinks in future research for repeated exposure effects on different modalities to enable more in-depth insight into the sensory characteristics of the products.

5 Conclusion

Flavor appears to be most sensitive to repeated exposure of food products. Importantly and in contrast to most previous studies, we can exclude that this finding is confounded by the difficulty of participants to evaluate smell, taste, and flavor independently. However, smell and taste familiarity also significantly increased after seven days of consumption suggesting that repeated exposure quickly enhances familiarity in adults in all three sensory modalities. In addition, changes in familiarity were significantly associated with changes in pleasantness for smell, taste, and flavor. Our results also highlight the importance of novelty for the effectiveness of repeated exposure, as effects were significantly stronger or solely observed for repeated consumption of the unfamiliar PD but not the familiar CD. We were also able to show that an acquired taste, likely driven by the umami taste quality, transfers to similar products and thus a generalization takes place. Taste, particularly umami, is therefore to be controlled in novel products to create a positive and familiar attitude toward the product and thus enable acceptance. Previous research has shown that exposure is an efficient strategy to increase food acceptance in children of different ages. We complement these findings by showing that repeated exposure is efficient in aiding the acceptance of protein-enhanced drinks for adults. Future research could investigate if these results can be transferred to other novel and reformulated foods. Our results are especially important, since the literature on exposure effects in adults is scarce, despite adults being a target group that may benefit from novel reformulated food.

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