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Beyond Distracted Eating: Cognitive Distraction Downregulates Odor Pleasantness and Interacts with Weight Status

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Abstract: Considering the widespread issue of distracted eating, our study explores how cognitive distraction influences the sensory perception of food-related odors among individuals with varying weight statuses. We used the Tetris game to mimic the dynamic nature of real-life cognitive distraction. Participants, categorized into a lean and an overweight/obese group based on their body mass index (BMI), rated odor intensity and pleasantness under low and high distraction conditions. Respiratory movements were monitored to ensure accurate assessment of sensory perception. No significant effects of distraction on odor intensity ratings were established. However, our findings reveal a significant reduction in odor pleasantness under high cognitive load, more pronounced in lean participants compared to those with overweight. Moreover, we observe an interaction between sex/gender and cognitive distraction effects in odor pleasantness perception. The differential effects of distraction across weight status groups and sex/gender are discussed in the context of hedonic motivations and compensatory mechanisms at play. This study sheds light into the mechanisms of distracted eating from the sensory perspective, that can pave the way for more personalized and effective strategies for promoting healthier eating habits in a world dominated by distractions.

Keywords: distracted eating; odor perception; odor intensity; odor pleasantness; obesity; hedonic eating

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1. Introduction

In our fast-paced society, distracted eating – when meals being consumed in parallel with other activities – has become increasingly prevalent. Eating in distraction-rich environments, like watching TV [1–3], in front of other screens [4–6] or while driving [7], is linked to overconsumption and higher body mass index (BMI). It is thus obvious to claim distracted eating as a contributing factor to the current obesity pandemic.

Several mechanisms have been proposed to explain why distracted eating leads to overconsumption. It is evident that attention that is drawn away from eating impedes the ability to adequately monitor food intake and hinders perception of internal signals of fullness, resulting in overeating [8]. Moreover, distraction during eating downregulates intensity perception of food flavor, potentially prompting overeating and altering preferences towards more palatable high-caloric foods. It is therefore essential to elucidate how distraction affects the sensory aspects of food, as this provides valuable insights into eating behavior and broader sensory interactions with our environment.

While flavor perception – an overall sensory experience of what we consume – is a complex interplay of all sensory modalities, odor perception is of pivotal significance in general and is of interest particularly for this study [9]. In fact, well before food is consumed, odor perception forms an anticipation of food intake, stimulates appetite, also shapes eating preferences and overall eating experience [10,11]. Furthermore, odors can impact mood and affective states, which in turn influence dietary choices [12,13]. Interestingly, even odors perceived unconsciously or non-attentively have potent power to impact food choices [14]. Odor perception is mainly characterized by hedonic valence, intensity and quality, features that collectively shape our olfactory experiences and interactions with our environment.

Prior evidence, primarily from our lab, demonstrates that odor perception, particularly odor intensity, is significantly affected by cognitive distraction. Using a memory task as a cognitive load paradigm, we found that reduced perception of odor intensity observed under high cognitive load was also evident at the neural level. Utilizing functional magnetic resonance imaging (fMRI), this study showed that distraction reduces activation in brain regions responsible for olfactory processing, including the piriform cortex, orbitofrontal cortex, and insula [15]. A follow-up behavioral study by Schadll et al., (2021) replicated the observed decrease in odor intensity perception under high cognitive load involving a more realistic cognitive load paradigm, the Tetris game [16].

Often, the hedonic valence – the degree to which an odor is perceived as pleasant or unpleasant – is a dominating if not the first and most important characteristic of an odor [17], greatly determining food choices but not limited to eating behavior. Pleasantness of odors is intricately linked to the reward system and especially relevant in the context of hedonic eating, prevalent in obesity [18,19]. To our knowledge, no studies have investigated how the hedonic valence of odors changes with increased distraction. This study was designed to answer this research question.

Despite the global rise in obesity rates, research on distracted sensory perception has predominately focused on individuals of normal weight and mainly females [20–23]. This is disappointing, as individuals with overweight or obesity constitute approximately 43% and 16% of the world's population, respectively [24]. As we strive to promote healthier eating habits on a global scale, it is crucial to understand the impact of distraction on smell perception in diverse populations, taking weight status and gender into consideration.

In the current study we also utilized the Tetris game as a cognitive task comprising low and high levels of distraction, since it offers a more realistic experience mimicking the dynamic cognitive distractions encountered in everyday life situations [25]. Moreover, the engaging nature of the Tetris game enables longer experimental duration without inducing boredom. To capture how sensory performance changes under distraction, we contrasted intensity and pleasantness ratings obtained in low and high cognitive distraction conditions. We then systematically compared the differences across conditions in participants with excessive weight and obesity to participants of normal weight across different genders. Importantly, breathing patterns are known to influence odor perception [26]. Therefore, we accounted for breathing variabilities when exploring effects of cognitive distraction on intensity and pleasantness ratings.

With regards to odor intensity, we hypothesized that cognitive distraction may have a greater influence in individuals with obesity, resulting in more profound decrease of odor intensity perception. The rationale behind is that obesity has been linked to diminished odor perception [27], impaired inhibitory control [28] and altered food reward processing [29]. Given the lack of prior research and the complex interplay between odor pleasantness perception and eating behavior, weight status and reward-driven choices, we hypothesized that changes in pleasantness perception under distraction would vary between participants of different weight statuses. However, we did not specify whether these changes would manifest as an increase or decrease in pleasantness perception.

The primary goal of this study was to provide novel insights on the effects of cognitive distraction on intensity and pleasantness perception of odors, highlighting the role of weight status and gender, while addressing the raised limitations of the prior studies.

2. Materials and Methods

2.1. Participants

Participants were recruited via flyer distribution, online advertisements, and word of mouth. Participation in the study was granted when meeting the following criteria: 1) body mass index (BMI) between 18.5 and 40 kg/m², 2) scoring less than 19 on the Beck Depression Inventory (BDI, [30]), 3) no pregnancy or breastfeeding, 4) no known, untreated, thyroid dysfunction, 5) no respiratory diseases, 6) no chronic metabolic or neurological diseases, 7) no smoking. The final study sample was composed of 59 participants. Following the definition provided by the World Health Organization, the participants with 18.5 ≤ BMI ≤ 24.9 kg/m² would form a lean group and participants with BMI range from 25 to 40 kg/m² would be assigned to the overweight/obese group. In other words, participants with excess weight and those classified as individuals with obesity were pooled together in one group. The formed groups were only relevant for the analysis purpose. Our lean group consisted of 30 (15 males) lean subjects (mean age = 26.7 years, standard deviation (SD) = 6.4, range = 19 – 43 years; mean BMI 22.2 kg/m², SD = 1.7 and range 19.5 – 24.8 kg/m²); another 29 (16 males) subjects formed an overweight/obese group (mean age = 28.79 years, SD = 6.72 and range 19 – 48 years; mean BMI = 30.24 kg/m², SD = 2.58 and range 25.0 – 39.0 kg/m²). In this manuscript, we define "gender" as a binary construct, including both biological sex and individual self-identification. This definition is based on the fact that all participants identified themselves as either male or female when presented with additional options ("non-binary", "diverse", "your option").

On the day of the experiment, participants' BMI was measured and calculated as weight (kg)/height (m)² and, if required, self-reported values were corrected. To confirm normosmia of all participants, we performed the 16-items Sniffin' Sticks identification (SSI) test [31]. If a participant identified less than 11 out of 16 odors correctly, their participation in the study was terminated. In total, 3 participants were excluded due to failing the SSI.

The formed study groups did not differ statistically based on age, SSI scores and BDI scores (p = 0.21, 0.68 and 0.148 accordingly), but on BMI scores ($p < 0.001$).

Subjects were asked not to eat anything, not to smoke tobacco, and to drink only water one hour before the experiment to avoid various influences on the olfactory system. Before the experiment, the participants were informed verbally and in writing about the study procedure and that they have the right to withdraw from the study at any moment. All participants signed a written informed consent form and data security statement prior to inclusion into the study. After the completion of the study all participants were monetarily compensated. The study was approved by the ethics committee of the University Hospital Erlangen (project number: 128_21 B) and complied with the revised declaration of Helsinki. This study is a part of a larger ongoing study exploring the effects of cognitive distraction on chemosensory perception and processing across volunteers of various weight status.

2.2. Olfactory Stimulation

During a piloting phase (n = 11), four food-associated odors covering a broad range of the pleasantness spectrum were selected. All odor stimuli (but coffee) were diluted with propylene glycol and concentrations were calibrated to achieve similar perceived intensity. The final stimulus pool consisted of these five odors: *beef* (Symrise AG, Holzminden, Germany; beef aroma type cooked, 10%), *cheese* (Symrise AG, Holzminden, Germany, pizza aroma type Margherita, 7.5%), *coffee* (Edeka Zentrale Stiftung & Co. KG, Hamburg, Germany, powder, 100% Arabica), *mango* (CPL Aromas Ltd., UK, Mango AR681772, 10%) and odorless (*empty*) stimulus represented by pure propylene glycol. Implementation of the odorless condition within the study served a double purpose: enabling olfactory receptors "to rest" between the odorous stimuli to create an effective, yet comfortable experience for the participants and serving as a control condition. Odors were stored in the refrigerator and put to room temperature at least an hour before the actual experiment started to ensure equal smell quality for each testing. A computer-controlled olfactometer was set up for odor delivery, delivering a constant air flow of 3L per minute [32]. Constant air flow was delivered to the participants across the entire experiment with odor stimulation embedded into it. Each of five odors was delivered simultaniously to both nostrils in a block design manner with 2s of stimulation and 4s of rest. In each trial, only one odor was presented for four times in the 24s that formed a sensory stimuation window.

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2.3. Procedure

The study employed the Tetris-game paradigm, as detailed by Schadll et al. (2021), to serve as the cognitive distraction framework. This framework introduced two levels of cognitive distraction, categorized as low and high, which were created by varying the speed of falling blocks in the game. The experimental session lasted around 50 minutes and consisted of two parts: the practice part followed by the main experiment. The practice part was implemented to accustom subjects to the odor's variability and the application setup and ensure the knowledge of the controls of the Tetris game. Questions were allowed at any point during this part. In this part, each stimulus was presented twice for 3.5s. After each odor presentation, subjects provided a rating of perceived intensity and pleasantness of the stimulus. Subjects were informed that there were possibly trials when they would not smell anything, referring to the trials with empty odorless stimulus. After the last odor presentation, participants saw the instructions for the Tetris game on a screen and played a brief introduction trial to get used to the key bindings.

In the following experimental part, participants were instructed to play the Tetris game to the best of their ability and to evaluate how intense and how pleasant they perceived an odor as well as how difficult each Tetris-game trial was. A 100mm visual analogue scale was utilized for each of the ratings with the left (lowest) anchor labeled as "not at all" and the right (highest) labeled as "very". To ensure the cognitive distraction paradigm, we used, indeed elicited two sufficiently distinct levels of cognitive load, we monitored the Tetris-game performance along with reported difficulty of each trial. The number of rows successfully cleared in each Tetris trial – Tetris scores – provided objective information whether the game performance dropped during the high cognitive load condition. Meanwhile difficulty ratings contributed to subjective perception of cognitive load manipulation. Note that participants were not aware of the real focus of the study to not bias their responses.

In total, there were 40 trials of the experiment, with each lasting 48s (see Figure 1). During each trial, participants first played the Tetris game with no odor stimulation for 24s and then another 24s with stimuli applied in the manner described earlier. Such design assured the immersion effect of the Tetris game. When ready, participants could press a button to start a new trial. During the experiment, each odor was presented during eight trials, four times in a low cognitive load condition and four times in a high cognitive load condition. The odor presentation was randomized with no direct repetitions of the same smell modality on two consequent trials.

Additionally, to elucidate potential effects of satiety on perceived odors, we accessed participants' hunger level by means of the 100mm visual analogue scale at the various times during the experiment: in the beginning of the practice session, in the middle and after the last trial of the experiment.

For the whole duration of the experiment, participants wore headphones playing white noise to mask the noise of stimuli delivery and the surrounding noises to avoid unprompted distraction. The experiment was designed and executed using PsychoPy3 software [33]. A keyboard was used to navigate the Tetris game.

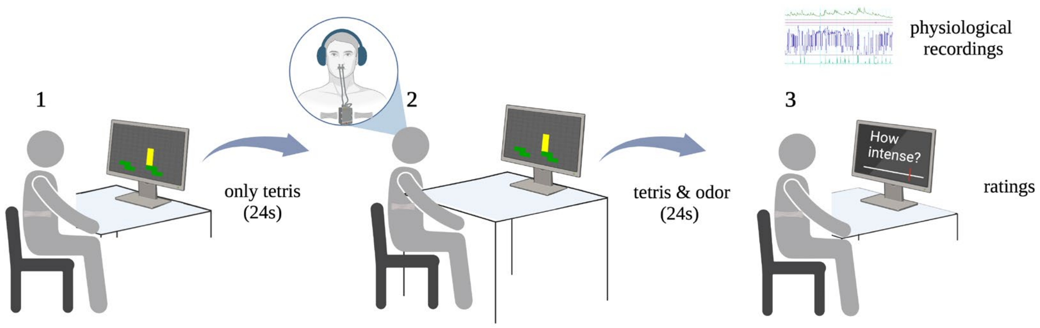

Figure 1. Graphical depiction of a trial. 1. Participant plays the Tetris game. 2. Participants continues to play the Tetris game while an odor is being delivered via the setup demonstrated in a magnified circle. 3. After 48s of the Tetris game, participant provides the ratings on intensity, pleasantness and

difficulty. For the whole duration of the experiment, respiratory data and skin conductance data are recorded. Created with BioRender.com.

2.4. Physiological Measurements

Together with the behavioral performance, the physiological parameters such as breathing patterns and skin conductance response (SCR) were recorded during the study. To detect possible variations in breathing patterns between low and high cognitive load conditions, which may affect perception of the stimuli and impact the ratings participants provide for each odor, participants wore a respiratory belt transducer (ADInstruments Ltd., Oxford, UK) which measured respiratory movements. Numerous research studies have shown that high cognitive load induces physiological alterations, which can be detected by analysing changes in skin conductance response. Thus, with two electrodes (LT118F GSR Finger Electrodes, ADInstruments Ltd., Oxford, UK) placed on the palmar surface on the middle phalanx of index and middle finger of the left hand we recorded SCR. We anticipated observing higher skin conductance response values during high compared to low cognitive load conditions. All physiological data was recorded via ADInstruments (Oxford, UK) software and by PowerLab model 4/26 with FE116 GSR Amp (ADInstruments Ltd., Oxford, UK).

2.5. Statistical Analysis and Physiological Data Processing

Behavioral data was analyzed with the software JASP, version 0.17.2.1 (JASP Team (2024)). To calculate effects of cognitive distraction, linear mixed models were computed. Multiple comparison correction was applied to the p-values using the Bonferroni method. Corrected estimates and confidence intervals are reported throughout the manuscript. The odorless stimuli were not included into the stimulus pool for the analysis unless specified otherwise.

We computed a linear mixed model on Tetris scores and one on difficulty perception with fixed factor cognitive load (low, high) and the random factor of participants for difficulty ratings and Tetris scores separately. To investigate a potential link between provided intensity and pleasantness ratings and the BMI, we ran a correlation analysis using Pearson´s coefficient. A dependent t-test was conducted on satiety ratings obtained in the beginning, in the middle and at the end of the experimental session. The α level for all tests was set to 0.05.

For the physiological data analysis, precise time of each experimental event was used to extract the SCR signal and respiration data in event-related fashion. A Python-based program was written to allow reading files with physiological data recorded by LabChart software. Then this physiological data was converted to the generalized biosignal. Using an open-source Python package NeuroKit2 [34], we further processed the SCR to phasic and tonic components; the latter being used for the analysis. With regards to the respiratory signal, we first cleaned the data to identify peaks, which allowed us to determine the respiratory rate. By counting these peaks over a one-minute period, we obtained breaths per minute (BPM), which was then used in our analysis. Physiological data of two participants was excluded due to a technical issue during the experiment, preventing data from being correctly recorded. Outlier identification analysis by visual inspection using Box plot graphs and high-pass filter set at 30 breaths per minute led to exclusion of 201 trials (8.51%).

3. Results

3.1. Distraction Induces a Reduction of Pleasantness Perception

To test our hypothesis that cognitive distraction might influence hedonic perception of food-related odors, we computed a linear mixed model on pleasantness ratings with the fixed factors *cognitive distraction* (low, high), *gender* (female, male), *group* (lean, obese) and *odor* (beef, cheese, coffee and mango) and a random factor of *participants*. Cognitive distraction significantly influenced pleasantness perception [F (1, 72.10) = 7.58, p = 0.007], such that odors were perceived on average as less pleasant under high (M = 44.19, SD = 30.01) in comparison to low cognitive load (M = 46.17, SD = 31.03) (see Figure 2). Further inspection revealed that with rise of distraction pleasantness perception decreased in comparable fashion across both weight groups. Yet, the effect reached statistical

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significance only in participants in the lean group (estimate = 1.95, SE = 0.91, 95% [0.14, 3.74], p = 0.035) and was rather a statistical trend in the overweight/obese group (estimate = 1.67, SE = 0.93, 95% [-0.16, 3.51], p = 0.064). Analysis revealed significant interaction effect of cognitive distraction x gender [F (1, 72.10) = 5.68, p = 0.020]. A closer pairwise comparison revealed that decrease in pleasantness perception with increased cognitive distraction reached significance in the male cohort (estimate = 3.37, SE = 0.90, 95% [1.60, 5.14], p < 0.001), but not in the female cohort (estimate = 0.24, SE = 0.95, 95% [-1.62, 2.11], p = 0.791). When averaged across both levels of cognitive distraction, ratings of odor pleasantness did not vary based on factors gender [F (1, 55.01) = 2.62, p = 0.110] or group [F (1, 55.01) = 0.07, p = 0.78]. We however observed an interaction effect of group x odor [F (1, 55.0) = 5.70, p = 0.002]. A closer look revealed that beef odor (Mean Difference = 13.49, t = 6.25, p < 0.001) and cheese odor (Mean Difference = 8.73, t = 4.06, p = 0.001) were perceived as more pleasant by participants in lean group, while coffee odor was found more pleasant by the participants in the overweight/obese group (Mean Difference = 17.19, t = 7.99, p < 0.001). Pleasantness ratings of mango odor did not differ across groups (p = 1.00). A two-way interaction of gender x odor also s an effect on pleasant ratings, such that female participants liked cheese odor (Mean Difference = -12.19, t = -5.55, p < 0.001) sufficiently less when compared to the male participants. As expected, pleasantness ratings varied significantly across odor modalities (averaged across groups, gender and cognitive distraction). Predictably, mango odor was rated as the most pleasant (M = 71.96, SD = 21.83, p < 0.001) followed by coffee odor (M = 52.50, SD = 28.98, p < 0.001), beef odor was on average rated as rather unpleasant (M = 34.62, SD = 24.03, p < 0.001) while cheese odor was perceived as least pleasant (M = 21.44, SD = 20.59, p < 0.001). We then tested if there are any observed effects on the odorless stimulus. Results revealed that pleasantness ratings did not vary across high (M = 44.74, SD = 17.77) and low (M = 44.83, SD = 19.02) levels of cognitive distraction [F (1, 464) = 0.024, p = 0.877).

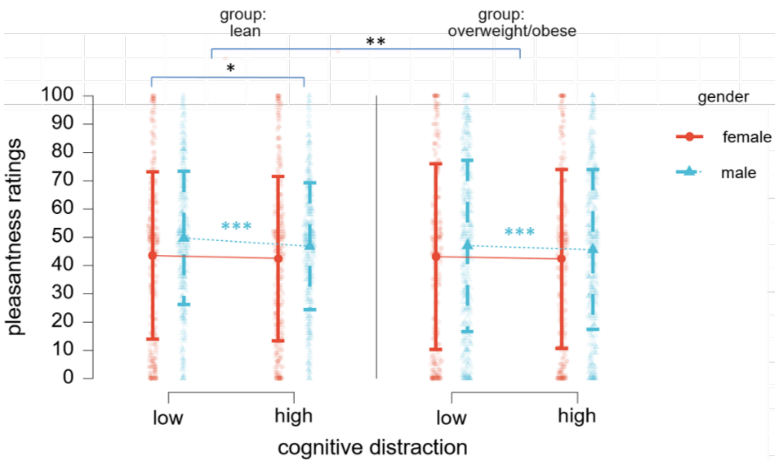

Figure 2. Distraction related decrease in pleasantness rating is shown across the weight statuses. Gender-related changes are color coded. * p < 0.05, ** p < 0.01, ***p < 0.001.

To further examine how variability in respiration could impact odor pleasantness perception, we computed a linear mixed model with the same fixed factors of *cognitive distraction*, *gender*, *group*, and *odor*, additionally including *breathing rate* per minute as a factor. Results confirmed a main effect of cognitive distraction [F (1, 73.59) = 5.01, p = 0.028] and odor [F (3, 44.27) = 14.22, p < 0.001] and no effect of group [F (1, 55.01) = 2.62, p = 0.110] on pleasantness ratings. The same interaction effect between group x odor was noticible [F (1, 55.01) = 2.62, p = 0.041]. This time, however, results implied that pleasantness ratings were significantly impacted by gender [F (1, 44.67) = 2.99, p = 0.041], in particular, female participants perceived odors as less pleasant (M = 41.09, SD = 32.69) when compared to male participants (M = 47.14, SD = 28.31). Moreover, effect of respiration rate on pleasantness ratings reached significance [F (1, 46.31) = 11.40, p = 0.001] elucidating that participants took more breaths per minute when odors were of higher perceived pleasantness. This observation

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has been further confirmed by the correlation analysis, which results show a weak positive correlation between pleasantness ratings and breathing rate ($r = 0.075$, $p < 0.001$).

3.2. Effects of Distraction on Intensity Perception Interact with Gender and Breathing Patterns

To elucidate impact of cognitive distraction on odor intensity perception, we computed a linear mixed model on intensity ratings with the fixed factors *cognitive distraction* (low, high), *odor* (beef, cheese, coffee, mango), *group* (lean or overweight/obese), *gender* (female/male), and the random factor of *participants*. Results indicated no significant main effect of cognitive load [F (1, 0.27) = 0.013, p = 0.903] or group [F (1, 55.03) = 1.99, p = 0.164]. Gender influenced the ratings of intensity perception, although the effect did not reach the conventional α threshold of 0.05, but was suggestive of a statistical trend [F (1, 55.03) = 3.11, p = 0.075]. On average, female participants rated odors as more intense (M = 70.10, SD = 23.09) compared to male participants (M = 63.26, SD = 22.36). The odor modality had a significant effect on intensity perception [F (3, 55.03) = 19.35, $p < 0.001$]. Follow-up pairwise comparison revealed that beef odor (M = 58.35, SD = 24.36) was perceived as significantly less intense compared to all other odor ($p < 0.001$). Cheese odor (M = 71.96, SD = 22.37) in turn was reported to be the most intense ($p < 0.05$). Odor of mango (M = 67.55, SD = 20.95) and coffee (M = 68.13, SD = 21.88) were of similar intensity (p = 0.975). There was a significant interaction effect of odor x cognitive distraction x gender [F (3, 102.79) = 2.79, p = 0.044]. Further inspection revealed a crossing interaction, with intensity perception going opposite direction between genders (see Figure 3). Yet, no significant differences were observed between any of the pairs during the post-hoc analysis.

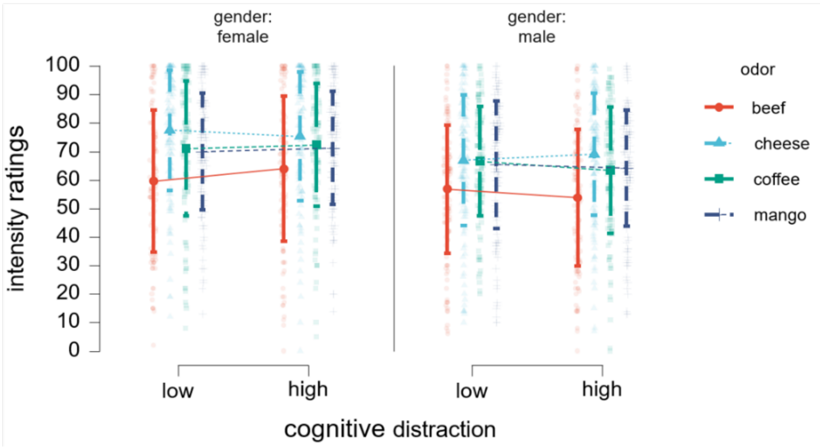

Figure 3. Changes of intensity ratings between cognitive load conditions (low, high). Intensity ratings from female and male participants are depicted in separate columns. Horizontal lines depict responses for each odor stimulus. An opposite distraction-related effect across genders is depicted.

As a next step, we investigated how breathing patterns contribute to the changes of intensity perception. We thus included breathing rate per minute (BPM) as an additional factor to the above-mentioned linear mixed model computed on intensity ratings. Effect of odor, gender and group on intensity perception stayed uneffected with inclusion of breathing rates. There was no main effect of breathing rate on intensity perception [F (1, 20.60) = 1.34, p = 0.266], but the effect of cognitive load became evident [F (1, 78.70) = 4.34, p = 0.040]. Hovewer, we also observed an interaction effect of cognitive load x breathing rate [F (1, 89.11) = 4.83, p = 0.030]. Resolving the interaction revealed that moderate effect of cognitive load was only visible in trials with highest breathing rate range (22-30 breaths per minute) (Figure 4). Specifically, intensity perception decresed in high cognitive load condition (M = 64.72, SD = 22.14) compared to low cognitive load condition (M = 67.79, SD = 20.90, mean difference = -3.34, t = -1.91, $p_{bonf.}$ = 0.056) while breathing rate did not vary between low (M = 22.9, SD = 2.41) and high (M = 23.18, SD = 2.51, p = 0.79) levels of cognitive distraction. No other

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interaction effects that reached significance were observed. Note, there were fewer data points within this breathing range, thus results should be treated with caution.

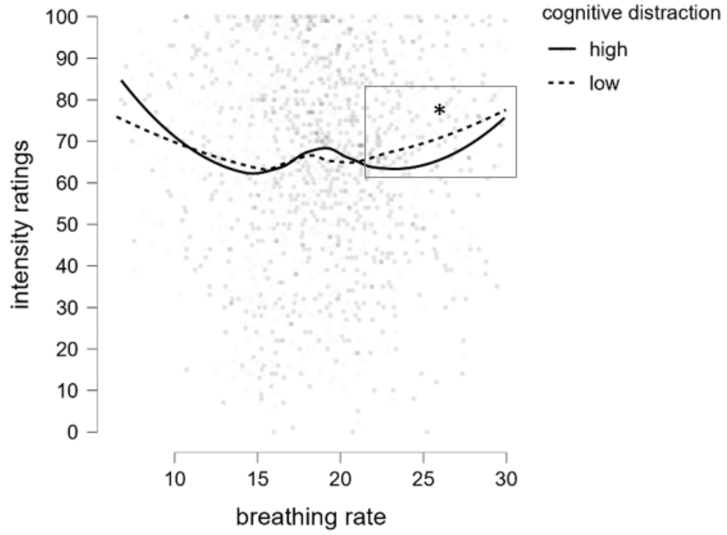

Figure 4. Changes in intensity ratings related to the number of breaths per minute (BPM). Values across low and high cognitive load are represented as separate lines. Decrease of intensity perception during high level of cognitive load in BPM range of 22-30 is highlighted. * p < 0.1.

3.3. Olfactory Sensitivity and Weight Status

Contrary to the common assumption that obesity is associated with reduced olfactory sensitivity, results of this study reveal the opposite effect. Specifically, BMI is positively correlated with odor intensity ratings, highlighting higher sensory sensitivity in participants with overweight or obesity (r = 0.085, p = 0.017). Moreover, positive association between intensity perception of odor stimuli and BMI was similarly expressed across genders (female: r = 0.128, p < 0.001; male: r = 0.210, p < 0.001). Interestingly, heightened sensitivity to the olfactory stimuli did not result in altered pleasantness perception as a function of BMI (female: = -0.017, p = 0.696, male: r = -0.006, p = 0.579).

As a next step, we investigated how satiety levels might influence perception of odors. Results of a correlation analysis revealed that intensity ratings decreased with rise of the ratings of satiety (r = -0.056, p = 0.008), while pleasantness ratings were not affected by differences in satiety (r = 0.028, p = 0.189). On average, difference between satiety ratings provided at the beginning (M = 32.78, SD = 27.80) and at the end of the experiment (M = 30. 74, SD = 30.25) did not reach statistical significance (p = 0.416).

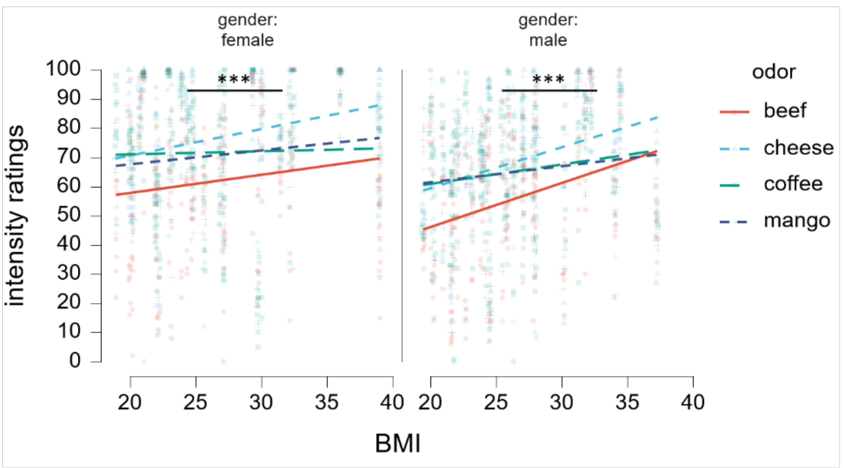

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Figure 5. Positive correlation between the intensity ratings and the body mass index (BMI). Effects are presented separately across genders with each odor depicted by a different color. *** for $p < 0.001$.

3.4. Physiological Data and Cognitive Distraction Paradigm

To assure the cognitive paradigm we used – the Tetris game – induced two sufficiently distinct levels of cognitive distraction, we compared subjective ratings of perceived trial´s difficulty and participants' game performance across trials assigned to low or high level of cognitive distraction. As expected, the Tetris score, the number of successfully cleared rows within one trial, was significantly lower in high distraction condition (M = 1.01, SD = 1.95) [F (1, 48.66) = 64.28, $p < 0.001$] compared to the low distraction condition (M = 1.95, SD = 1.54). On average, participants rated trials within high distraction condition as significantly more difficult (M = 64.99, SD = 22.36) in comparison to the trials assigned to the low distraction condition (M = 20.35, SD = 20.58) [F (1, 50.17) = 279.63, $p < 0.001$]. On a physiological level, values of skin conductance response did not significantly differ between cognitive load conditions [F (1, 55.98) = 0.44, p = 0.505].

To address a question potentially interesting to the audience, whether the odor modality in turn could influence the Tetris game performance, we conducted another exploratory analysis. The speculative idea behind this was that the coffee odor could elicit effects similar to caffeine intake, such as improving concentration and resulting in a higher Tetris score. More broadly, pleasantness perception could influence the game performance or the perception of difficulty, particularly when odors are either aversive or pleasant. To test this assumption, we computed two linear mixed models: one on the Tetris scores and one on difficulty ratings with fixed factor *odor* and random factor of *participants*. Results indicated that the odor modality neither affected Tetris score [F (4, 937.66) = 0.27, p = 0.893] nor difficulty perception of the Tetris game [F (4, 784.53) = 0.47, p = 0.755].

Yet, pleasantness perception interacted with the Tetris scores and perceived difficulty. Specifically, among female participants across both weight statuses, pleasantness ratings correlated positively with Tetris scores (r = 0.105, $p < 0.001$) and negatively with difficulty ratings (r = -0.067, p = 0.023). With regards to the weight status, participants in the obese group scored higher in Tetris game when providing greater pleasantness ratings (r = 0.085, p = 0.005) and ratings of difficulty were correlated with a decrease in pleasantness ratings and in the lean group (r = -0.063, p = 0.015). To conclude, we here observed effects of cognitive distraction in lean participants, while pleasantness correlates with the performance in females and participants with obesity.

4. Discussion

Within the context of the increasingly prevalent phenomenon of distracted eating and its contribution to the global rise in obesity, our study moves beyond the traditional focus on calorie intake to examine how cognitive distraction influences sensory perception. Considering the prominent role olfaction plays in eating behavior, we investigated the effects of cognitive distraction on the perception of food-associated odors. In our study, using a realistic and engaging cognitive distraction paradigm – the Tetris game – we explored how odor perception, in terms of pleasantness and intensity, changes under distraction for participants of different weight groups.

Our findings reveal that odor pleasantness is significantly diminished under high cognitive load. Noteworthy, the effects of distraction on odor pleasantness are modulated by the weight status, in that pleasantness ratings decrease with a rise of cognitive distraction predominantly among lean participants. This differential response can be attributed to the distinct hedonic motivations and eating behaviors across study groups. On the one hand, individuals with overweight and obesity often exhibit heightened reward sensitivity and greater prominence of hedonic eating, prioritizing the anticipated pleasure from food over its immediate sensory qualities [35,36]. This hedonic motivation could dominate the focus and overshadow the effects of distraction, rendering subjects with overweight less sensitive to changes in sensory pleasantness. On the other hand, the observed decrease in odor pleasantness during high cognitive load in lean individuals might act as a mechanism to prevent overeating by reducing the sensory reward value of food and lowering the likelihood of overconsumption when distracted. The opposite might be true as well: a decrease in

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pleasantness perception may promote overeating, to compensate for the reduced sensory satisfaction. Taken together, our results suggest that lean individuals may experience greater sensory disruption under distraction, potentially affecting appetite regulation, while those with obesity might maintain stable hedonic responses despite cognitive load. Although regular food consumption in distracted settings being among the largest predictors of heightened BMI, the complex interplay between the body weight and susceptibility to distraction is yet to be understood.

Beyond body weight, gender differences significantly contribute to variations in odor perception and eating behavior, orchestrated by distinct neurocognitive mechanisms. In obesity, food-related sensory cues have a stronger connection to reward-driven mechanisms among women, while eliciting higher activation in somatosensory regions in men [37,38]. In alignment with this, we observe an interaction between gender with effects of cognitive distraction. In detail, under a high level of distraction odor pleasantness significantly decreases in male, but not in female participants. One possible explanation is that cognitive distraction disrupts the integration of olfactory information in somatosensory regions, leading to reduced odor pleasantness in males. In contrast, due to being more strongly linked to reward processing, odor pleasantness perception in females remains intact, reflecting the resilience of reward pathways against distraction. Following this line of thought, our results show that females perform better in the Tetris game when exposed to the more pleasant odors. Again, this might be due to a close link between odors and emotional/reward processing, enhancing focus and cognitive efficiency [39]. Importantly, our results are not influenced by differences in the respiratory patterns, allowing us to assume they are indeed induced by distraction and are modulated by interindividual and/or group differences. Furthermore, the absence of a significant difference in pleasantness ratings across both distraction conditions between lean and overweight/obese groups further supports the notion that the varying pleasantness ratings under distraction are not due to inherent differences in sensory perception.

In broad terms, reduced pleasantness of odors might affect food-related behaviors, such as the acceptance of novel foods. When individuals are distracted, their reduced sensitivity to odor pleasantness may make them less likely to try and accept unfamiliar foods, as pleasant sensory experiences often facilitate the willingness to explore and accept new flavor options. Beyond food consumption, the decrease in odor pleasantness due to distraction may have broader implications for daily life experiences. Odors contribute to social interactions and emotional well-being, while enhancing mood and reducing stress [26,40,41]. The consistent reduction in odor pleasantness due to distraction could diminish these benefits and impact various aspects of quality of life, from healthcare to consumer experiences.

With regards to intensity perception, in our study we could not replicate prior findings demonstrating a decrease in odor intensity perception under distraction [15,16]. The difference in the outcome could not be attributed to the variations in the study design since the same Tetris paradigm was used to induce cognitive distraction [16], yet it might be driven by the sensory properties of the study stimuli. Specifically, findings from the other studies across both taste and smell modalities suggest that the saliency of stimuli — primarily determined by their concentration levels or association with caloric density — appears to shape the distraction-induced effects. Notably, stimuli of high concentrations or those linked to high-caloric foods – like the odor stimuli used in this study (e.g., cheese, beef) – remained unaffected by distraction [15,18]. Besides, there is a possibility that the level of distraction applied in our study was insufficient to impact intensity perception of the study odors. The rationale is based on the observed trend of decreased intensity perception during the trials with elevated breathing rates, implying higher levels of difficulty and suggesting that a greater magnitude of distraction is required to affect intensity of the salient odor stimuli.

In the context of research on sensory sensitivity and obesity, we report a notable positive correlation between intensity ratings and BMI. This discovery supports the findings of Stafford & Whittle [42] but diverges from the commonly reported evidence of diminished olfactory function in obesity [43]. Together, it underscores the complexity of this relationship as well as the current lack of agreement on it in the existing literature.

We also observed gender-driven differences in the context of olfactory sensitivity. Averaged across both distraction conditions, female participants provided significantly higher intensity ratings across all study odors that resonates with prior suggestions of enhanced olfactory sensitivity among females [44].

Considering that high level of cognitive distraction distinctly influences odor intensity and pleasantness perception in our study group, it is reasonable to assume two distinct distraction-related mechanisms through which the sensory-specific (intensity) and the affective (pleasantness) characteristics of odors are influenced. The distraction-induced evidence from another sensory modality, taste, supports this dichotomy [45].

Despite the substantial contributions this work offers, several limitations warrant consideration. Our effects, though limited in size, align with prior research in the field reporting statistically significant yet relatively minor changes in olfactory and gustatory perception under distraction, reflecting the substantial interindividual differences characteristic of the chemical senses [15,16,21,45]. The open question that remains is whether the decrease in odor pleasantness ratings we have observed is sufficient to induce the altered food intake. Since neither intake, nor food choice behavior was investigated by this study our assumptions are purely based on the available knowledge from different research fields. Future studies should directly bridge the changes in sensory perception to the immediate and delayed consumption. Moreover, due to our limited understanding of the neural mechanisms orchestrating distraction-induced changes observed behaviorally, especially with regards to the weight statuses and eating strategies individuals opt for, there is a clear need to investigate this in the future.

Exploring eating behavior and individual differences as well as manipulating the saliency of sensory stimuli could provide further insights into why certain individuals are more susceptible to the effects of distraction. Furthermore, combining participants with overweight and those with obesity into a solitary group poses a limitation to our study. Future research should aim to differentiate between these groups to better understand the nuanced impacts of cognitive distraction on sensory perception.

In summary, our study underscores the critical need to elucidate how cognitive distraction impacts sensory aspects of food perception to better understand mechanisms associated with distracted eating. Moreover, our study emphasizes the importance of considering individual differences, including weight status and gender, when aiming to mitigate the negative consequences of distracted eating. Understanding these nuances can pave the way for more personalized and effective strategies to promote healthier eating habits and improve overall sensory interactions in a world increasingly dominated by distractions.

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