Effects of Hunger on Sympathetic Activation and Attentional Processes for Physiological Computing

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Abstract: Assessing users' states becomes increasingly important also for technical systems. In the present study, we assessed the influence of hunger on processing food versus household items by monitoring eye movements in a picture categorization task. As indicator for sympathetic activation, pupil dilation was additionally assessed in hungry and satiated participants. Food and household items were presented in the left and right visual field and the task of the participants was to indicate whether the pictures in both visual fields represented the same (household vs. food) or different categories (household and food). Although behavioural data did not differ between hungry and satiated participants, more thorough investigations of gaze behaviour showed that hungry participants were more impaired in processing household items than the satiated ones. In addition, mean pupil dilation differed between hungry and satiated participants. Pupil size was shown to correlate with hunger ratings suggesting that gaze-based measures can indeed serve as diagnostic tool for sensing user states.

1 INTRODUCTION

Current technical systems are expected to react to the intentions and dispositions of users. Hence, knowledge about basic motivations of users and their respective changes in behaviour are essential when realizing affective computing systems. The technical systems need to acquire their knowledge about the user's states by means of physiological measures. Therefore, it is important to know how users react to changes in bodily states as well as to respective relevant stimuli. In the current study, we assessed such physiological changes using the bodily state of hunger and corresponding food versus household images as relevant stimuli as an example.

Hunger is one of the most basic bodily dispositions. One might assume that hunger affects human attention and arousal. In addition, one might suspect that it affects attending either towards all stimuli or towards potentially eating-related stimuli only. In the current study, this was investigated by measuring eye movements and pupillary changes in hungry versus satiated participants watching comparable food and household images.

Hunger is known to influence many cognitive and emotional processes in everyday life, which is especially apparent in food-related behaviour: Empirical data demonstrate that food deprivation alters brain activation and subjective appeal to pictures of high- and low-calorie food (Giel et al., 2010; Goldstone et al., 2009; Piech et al., 2010) and modulates activity in the food reward system (Siep et al., 2009). It is also known that hunger is a potent activator of the sympathetic nervous system (Andersson et al., 1988; Chan et al., 2007; Pollatos et al., 2012); various studies could demonstrate that short-term food deprivation (up to 72 hours) leads to an increased sympathetic and decreased parasympathetic activation. For example, Chan et al. (2007) demonstrated that short-term fasting increased sympathetic activity as measured by heart rate variability (HRV) and 24-hour urinary catecholamines and decreased parasympathetic tone (HRV) in humans.

In this context the model of neurovisceral integration proposed by Thayer and Brosschot (2005) is highly interesting. It states that autonomic imbalance and reduced parasympathetic tone may be the final common pathway linking negative affective states to health problems, probably modulated by interface regions like the prefrontal cortex, which is a target region both for information from the central

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nervous system and attention, emotion and motivated behaviour networks (Thayer and Brosschot, 2005). A sympathetic activation and a parasympathetic withdrawal has been demonstrated to be linked to hypervigilance and inefficient allocation of attentional and cognitive resources (Thayer and Brosschot, 2005). A former study could show that food deprivation provokes a parasympathetic decrease and heightened sympathetic activity which was associated with a hypervigilance to pain stimuli both on a perceptual and emotional level (Pollatos et al., 2012).

There are already reports indicating that eye movements between hungry and satiated persons do not differ (e.g. Nijs et al., 2010). However, there are also observations that eye movements can be diagnostic for eating behaviour (Werthmann et al., 2011) in over-weight participants. Nevertheless, whether hungry and satiated person process food versus other images differently is still unclear. This was to be examined in the present study.

Moreover, in video-based eye tracking, also pupil dilation is given. As is evident, pupils of the eye are activated by sympathetic nerves (e.g. Ehlers et al., 2016; Partala and Surakka, 2003). Hence, pupillometry can serve as an indicator of sympathetic activation. As stated above, hunger is known to raise sympathetic activation. Hence, one would expect observing larger pupils in hungry relative to satiated participants.

Concerning food stimuli, numerous studies demonstrated that nutrition state of the subjects changed brain responses to food stimuli (Goldstone et al., 2009; Siep et al., 2009; Stice et al., 2013). For example, Goldstone and colleagues (2009) reported that fasting increased activation to pictures of high-calorie foods in various brain regions including the ventral striatum, the amygdala, the anterior insula, and medial and orbitofrontal cortex. Furthermore, fasting enhanced the subjective appeal of high-calorie foods, and the change in appeal bias towards high-calorie foods was positively correlated with medial and orbitofrontal cortex activation. The authors concluded that fasting biased brain reward systems towards high-calorie foods. Supporting these results, also Stice and co-workers (2013) reported that the duration of experimentally manipulated caloric deprivation correlated positively with activation in regions implicated in attention, reward, and motivation in response to food images (including the anterior cingulate cortex and the orbitofrontal cortex). They suggested that self-imposed caloric deprivation increases responsivity of attention, reward, and motivation regions to food, which may explain why caloric deprivation weight loss diets typically do not produce lasting weight loss (Stice et al., 2013).

These results are in accordance to Siep et al. (2009) who reported that hunger interacts with the energy content of foods, modulating activity in several regions (e.g. cingulate cortex, orbitofrontal cortex, insula). They showed that food deprivation increased activity following the presentation of high calorie foods and also followed that this fact may explain why treatments of obesity energy restricting diets often are unsuccessful. Extending these results, Frank and co-workers (2010) reported that high-caloric pictures compared to low-caloric pictures led to increased activity in food processing and reward related areas, like the orbitofrontal and the insular cortex, but furthermore they found activation differences in visual areas (occipital lobe), despite the fact that the stimuli were matched for their physical features. Frank et al. (2010) concluded that hunger and the calorie content of food pictures also modulate the activation of early visual areas. Having this in mind, other measures than imaging techniques that are rather slow in their response profile might help to disentangle early effects of hunger on visual processing of food stimuli.

Using other measures than imaging techniques, Hepworth and co-workers (2010) manipulated mood in healthy participants before using food stimuli in a visual-probe task assessing attentional bias. They showed that negative mood increased both attentional bias for food cues and subjective appetite. Attentional bias and subjective appetite were positively inter-correlated, suggesting a common activation of the food-reward system. Giel and colleagues (2011) used eye tracking in a free viewing paradigm: They reported that anorectic patients allocated overall less attention to food. Interestingly, attentional engagement for food pictures was most pronounced in fasted healthy control subjects.

Till now, the question of whether different levels of visual processing of food stimuli can be distinguished using eye tracking when manipulating hunger state in participants remains unanswered. As hunger essentially influences everyday behaviour and is an important variable in sensing the state of a person in interaction to his/her environment, the aim of the present study was twofold: First, we wanted to clarify whether hunger leads to an attentional bias for food pictures using different measures of eye tracking (direction of the initial fixation, first fixation duration, fixation count) allowing to distinguish perceptual from evaluating processes. Second, we aimed to elucidate whether pupillometry was a valid measure for a sympathetic increase associated with hunger.

2 METHOD

2.1 Participants

In total 51 psychology students (40 females and 11 males, $M_{age} = 22.61$, $SD_{age} = 3.92$) of Ulm University participated in this experiment for partial fulfilment of course credit. All participants did not report a history of eating disorder, had normal or corrected to normal vision and provided informed consent based on the guidelines of the German Research Foundation (DFG). Due to technical difficulties (calibration and data recording) the data of four participants were not included in the analysis of the gaze data during the food categorization task and six subjects were not included in the analysis of the influence of hunger on pupil size. Therefore, the sample for the food categorization task (see Procedure) consisted of 47 participants (26 hungry, 38 females, $M_{age} = 22.77$, $SD_{age} = 4.05$) and the final sample for the influence of hunger on pupil size consisted of 45 participants (25 hungry, 37 females, $M_{age} = 22.93$, $SD_{age} = 4.06$).

2.2 Stimuli and Apparatus

As stimuli the pictures of food (e.g. bread) and household items (e.g. handkerchief) used by Koch et al. (2014) to study the attentional bias towards food in overweight and obese children, were applied. The advantage of this stimulus set consists in the similar depiction of food and household items. Stimuli of both categories were presented on a white plate.

The experiment was run on a Windows 7 PC and was implemented using PsychoPy (Version 1.81.02; Peirce, 2007). The stimuli were presented on a Dell P2210 (resolution 1680 x 1050 px, refresh-rate 60 Hz) which was stationed approximately 60 cm from the participant. A remote eye-tracking system (RED250 with a sampling-rate of 120 Hz; SensoMotoric Instruments, Teltow Germany) was attached to the monitor and recorded gaze as well as pupillometric data. The experimental setup is illustrated in Figure 1.

Figure 1: Overview of the experimental setup.

2.3 Questionnaire Data

Besides the assessment of sociodemographic variables (such as age and gender), the participants were also asked whether they have suffered from any kind of eating disorder in their lifetime. Height and weight were assessed with a customary measuring device and a customary digital scale. Furthermore, the participants were asked to rate their subjective feelings of hunger on the 8-item visual analogue scale ranging from 0 to 10 of Flint, Raben, Blundell, and Astrup (2000, e.g. “How hungry are you?”).

2.4 Procedure

In preparation for the study, the participants in the food deprivation condition (n = 27) were asked not to consume any food, alcohol or caffeine beginning at 8:00 pm on the day prior to their individual study appointment, which was either until 8:00 am, 9:00 am or 10:00 am. In contrast, the participants in the satiated condition (n = 24) were asked not to change their eating habits.

After arriving in the laboratory the weight and size of the subjects were assessed and the participants rated their subjective hunger feelings on the visual analogue scale of Flint et al. (2000).

The experiment consisted of two parts. First, pupil size was measured and afterwards, the experiment aiming at exploring the processing of food and household items in satiated and hungry participants using eye-tracking was carried out.

The two parts of this experiment are now described in more detail.

2.4.1 Pupillometric Measurement Phase

Participants’ pupil size was measured for five seconds using the SMI RED250 eye-tracking system. To avoid eye-movements, participants were instructed to fixate on a black fixation cross, which was presented centrally with a size of 0.6° on a homogenously white screen (141.7 cd/m²). The luminance of the room was kept constant at 75.3 lx (including the luminance of the monitor).

2.4.2 Food Categorization Task

After the pupillary measurement phase, the food categorization task was carried out. At its beginning a 9 point calibration and 4 point validation was performed.

In the food categorization task, a trial started with the central presentation of a black fixation cross with a size of 0.6° for 1 s. Subsequently, two pictures (each 9° x 6°) were peripherally presented in the left and right visual field at an eccentricity of 9°. These pictures either consisted of food (F) or household (H) items (Koch et al., 2014; see Figure 1 for an illustration). Therefore, there were four different stimulus constellations: food items are presented on both sides (FF), household items are presented on both sides (HH), food items are presented on the left and household items on the right side (FH) and household items are presented on the left and food items are presented on the right side (HF). The task of the participants was to decide whether the objects shown in both visual fields were representing the same category (either both food or both household items) or whether mixed categories were presented in the left and right visual field. If the stimuli presented on both sides represented the same category participants were instructed to press the key 'l' on the right hand-side of a standard QWERTZ-keyboard. If the stimuli presented on both sides represented different categories participants were instructed to press the key 'a' on the left side of the keyboard.

The experimental block started with a short training phase consisting of four trials, in which the participants were familiarized with the task and the stimuli's appearances and categories. The test phase consisted of 64 trials, 16 for each stimulus combination (FF, HH, FH, HF). The order of the trials was randomized. During this test phase, the gaze position was continuously recorded.

2.5 Processing of the Oculomotor Data

2.5.1 Processing of Pupillometric Data

For processing of the pupillary signal, first, blinks and saccades were removed from the data stream. Further, values deviating more than 1.5 times the interquartile range from the median were treated as artefacts and were removed from the signal. The resulting missing values were replaced using linear interpolation.

2.5.2 Processing of the Eye-movements Data

For processing the gaze data, we utilized the Be Gaze (Version 3.5) software of SMI (SensoMotoric Instruments, Teltow Germany).

As areas of interest (AOI), the left and right stimuli were regarded. For these two AOIs, event statistics were computed and exported. Afterwards, the raw data were processed using Matlab R2015b (Mathworks Inc.). Trials with very high or low reaction times (median ± 1.5 interquartile range) were dismissed. Additionally, for each variable, subject and stimulus category an outlier analysis was performed. Values deviating more than three times the interquartile range of the median were not considered in the adjunct analysis. Finally, all dependent variables (initial fixation direction, first fixation duration and fixation count) were extracted separately for the different stimulus configuration (FF, HH, FH, HF) and both visual fields (left, right). In order to control for reliable computation of the mean, only data of participants were considered, which had at least eight remaining correct responses per condition after the procedure, described above, was carried out.

The data were descriptively and inferentially analysed using SPSS (Version 21, IBM).

3 RESULTS

3.1 Hunger Ratings

In order to check whether the instruction to resign for food during the last hours yielded in hungrier participants, the reported feelings of hunger were assessed. Since the eight items of the hunger scale of Flint et al. (2000) showed high internal consistency ($\alpha = .887$), the items were averaged and combined into one scale.

A t-test revealed that participants in the food-deprivation condition indeed reported higher hunger feelings than participants in the satiated condition ($t(30.47) = 4.92$, $p < .001$, $M_{hungry} = 7.12$ $SD_{hungry} = 1.30$, $M_{satiated} = 4.41$ $SD_{satiated} = 2.24$). Therefore, we conclude that the short-term food deprivation was successful in manipulating the participants' hunger state.

3.2 Analysis of the Behavioral Data

One can assume that hunger speeds up motor reactions and the processing of either stimuli independent of their content (food and non-food) or specific to the motivational relevant stimulus food. To examine this question, we analyzed the correctness and reaction times in the food categorization task. The purpose of this analysis was to investigate whether hungry and satiated participants differed on a behavioral level in processing the different stimuli (FF, HH, FH, HF). The percentage of correct responses of the food categorization task was entered in a repeated measures ANOVA with the within-subject factor stimulus (FF: food pictures are presented in both visual fields; HH: household items in both visual fields; FH: food items in the left and household items in the right visual field; HF: household items in the left and food items in the right visual field) and the between-subject-factor hunger (satiated vs. hungry). This analysis revealed a main effect of stimulus ($F(1.39,62.74) = 25.55$, $p < .001$, $\eta^2 = .362$). Participants gave most correct responses, when food items were presented in both visual fields (M = 95.3%, SE = 0.7%) and least correct response when household items were presented in both visual fields (M = 72.4%, SE = 3.6%). Mixed stimulus combinations were rated equally good at 89.3% (SE = 1.3%).

Reaction times for correct trials were entered in a repeated measures ANOVA with the within-subject factor stimulus (FF vs. HH vs. FH vs. HF) and the between-subject-factor hunger (satiated vs. hungry) for all 43 participants (24 hungry) who answered at least eight trials per stimulus combination (FF, HH, FH, HF) correctly. Again, the analysis revealed a main effect for stimulus ($F(1.74,71.35) = 36.98$, $p < .001$, $\eta^2 = .474$, see Figure 1). Participants reacted especially fast when food was displayed in both visual fields. They were slower when only household items were presented and when a combination of food and household items was shown. Furthermore, for trials with mixed stimulus categories, reactions were faster when food was displayed on the left side (FH) compared to when it was presented on the right side (HF). All other effects were not statistically significant ($F < 1$).

Summarizing, there was no difference between hungry and satiated participants, neither in percentage of correct responses nor in reaction times. Both dependent variables indicated that it was easiest to react to stimuli, when food was presented in both visual fields and that it was most difficult to react, when household items were presented on both sides.

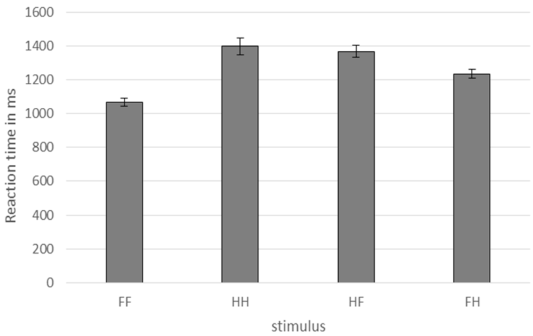

Figure 2: Reaction time in ms depending on the stimulus configuration (FF, HH, HF, FH).

3.3 Analysis of the Eye Movements Data

3.3.1 Initial Fixation Direction

One might assume that hunger produces a salience signal for food items, thus boosting the amount of initial fixations hitting the AOI containing food. Hence, the direction of the initial fixation towards either of the AOIs can be interpreted as the priority of a certain visual field.

The present data clearly show that most of the first fixations (M = 85.5%, SE = 0.02%) hit the left AOI. The percentage of first fixations hitting the left AOI was entered in a repeated-measures ANOVA with the within-subject factor stimulus (FF vs. HH vs. HF vs. FH) and the between-subject factor hunger (satiated vs. hungry). This analysis revealed that the percentage of initial fixations on the left AOI was independent of the factors stimulus, hunger and the interaction of both factors (all $F < 1.5$).

Summarizing, the data show that most of the initial fixations hit the left AOI independently of the stimulus which is displayed in the left or the subject's hunger state. This suggests that initial fixations mainly indicate a certain processing strategy rather than current user states.

3.3.2 First Fixation Duration

Considering the influence of hunger one might also suppose that hunger results in a faster processing of food stimuli. To examine this idea, the duration of the first fixations on food versus household items was analysed. The durations of the first fixation towards the left AOI were entered in a repeated-measures ANOVA with the within-subject factors stimulus-left (household vs. food) and stimulus-right (household vs. food) and the between-subject-factor hunger (satiated vs. hungry).

The ANOVA revealed a significant main effect of stimulus-left ($F(1,36) = 5.11$, $p = .03$, $\eta^2 = .124$): That is, independently of the hunger state, participants fixated longer on the left AOI, when household items were presented compared to food items ($M_{household}$ = 234.56 ms, $SE_{household}$ = 6.45 ms; M_{food} = 222.27 ms, SE_{food} = 6.29 ms, see Table 1 for an overview of the pattern of results). The other effects were not significant (all $F < 1.5$).

Table 1: Mean duration of first fixation in ms on the left AOI depending which stimulus category is presented in the left (household vs. food) and in the right visual field (household vs. food).

		right visual field	
		household	food
left visual field	household	M = 234.74 SE = 8.37	M = 234.38 SE = 6.93
	food	M = 224.04 SE = 6.98	M = 220.49 SE = 7.07

A similar picture emerged for the right AOI. The analysis revealed a main effect of stimulus-right ($F(1,36) = 7.96$, $p = .008$, $\eta^2 = .181$), also reflecting the fact that participants fixated longer on the right AOI when household items were presented compared to food items ($M_{household} = 308.78$ ms, $SE_{household} = 9.81$ ms; $M_{food} = 288.22$ ms, $SE_{food} = 8.17$ ms). Besides this effect of stimulus category, the analysis showed a main effect of hunger ($F(1,36) = 6.62$, $p = .014$, $\eta^2 = .155$): The duration of the first fixation on the right AOI was longer for hungry participants compared to satiated ones ($M_{hungry} = 319.75$ ms, $SE_{hungry} = 11.05$ ms; $M_{satiated} = 277.26$ ms, $SE_{satiated} = 12.28$ ms). The other effects were not statistically significant (all $F < 2.5$).

Summarizing, the data showed that participants' first fixation on an AOI was longer when household items were presented at the respective side compared to food items. Furthermore, on the right AOI the first fixation was longer for hungry participants.

3.3.3 Fixation Count

Since hunger can be thought to increase the interest into food stimuli and the ease of processing of either all or only motivational relevant stimuli, also, the number of fixations on either AOI was investigated. We again conducted repeated-measures ANOVAs with the within-subject factors stimulus-left (household vs. food) and stimulus-right (household vs. food) and the between-subject factor hunger (satiated vs. hungry).

First, the results regarding the amount of fixations on the left AOI are considered. The analysis revealed that fixations on the left AOI were more frequent when household items were presented compared to when food was presented in the left visual field (main effect for stimulus-left: $F(1,31) = 18.62$, $p < .001$, , $\eta^2 = .375$). The interaction of stimulus-left and hunger was significant ($F(1,31) = 6.03$, $p = .020$, $\eta^2 = .163$, see Figure 2), indicating that hungry participants fixated more often on household compared to food items than satiated ones did. Besides, the interaction of stimulus-left and stimulus-right reached significance ($F(1,31) = 12.03$, $p = .002$, $\eta^2 = .280$): When household items were presented in the right visual field, the amount of fixations on the left AOI was independent of stimulus category in the left ($M_{household} = 2.17$, $SE_{household} = .079$; $M_{food} = 2.15$, $SE_{food} = .10$). However, for food items in the right visual field the amount of fixations was higher when household items ($M_{household} = 2.38$, $SE_{household} = .091$) compared to food items were presented in the left visual field ($M_{food} = 1.90$, $SE_{food} = .078$). The other effects were not statistically relevant (all $F < 2.5$)

Second, the analysis for the amount of fixations on the right AOI is reported. The repeated-measures ANOVA revealed a main effect for the factor stimulus-right ($F(1,31) = 6.40$, $p = .017$, $\eta^2 = .171$). As for the left AOI, there were more fixations on the right AOI when household-items were presented than when food items were presented ($M_{household} = 1.85$, $SE_{household} = 0.05$; $M_{food} = 1.73$, $SE_{food} = 0.06$). Furthermore, there were more fixations on the right AOI, when household items relative to food items were presented in the left visual field (stimulus-left: ($F(1,31) = 12.60$, $p = .001$, $\eta^2 = .289$; $M_{household} = 1.87$, $SE_{household} = 0.06$; $M_{food} = 1.70$, $SE_{food} = 0.05$). The other effects were not statistically significant (all $F < 1.5$).

Summarizing the important results concerning our question at issue, the amount of fixations was higher on household items than on food items. For the left AOI the amount of fixations on household items was even higher for hungry compared to satiated participants.

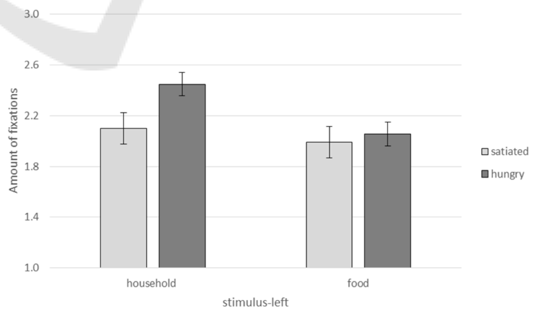

Figure 3: Amount of fixations on the left AOI depending on the stimulus presented in the left visual field and hunger. Error bars reflect the standard error of the mean.

3.4 Analysis of the Pupillometric Data

Due to the algorithm outlined in the method section in average 9.7% ($SD = 8.2\%$) of data points were

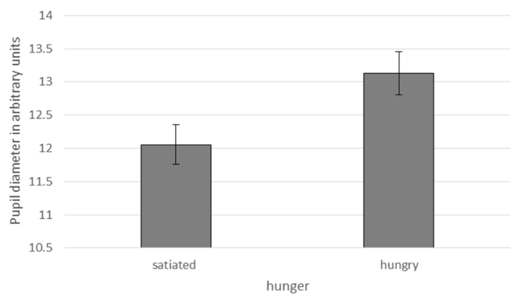

Figure 4: Mean pupil diameter in dependence of hunger. Error bars reflect the standard error of the mean.

treated as artefacts and were replaced using linear interpolation. The pupillary data were then averaged over the 5 s recording time. An independent samples t-test revealed larger pupils for hungry compared to satiated participants ($t(43) = 2.40$, $p = .021$, $\Delta M = 1.08$, $SE = 0.45$, see Figure 3). Importantly, pupil size and the individual ratings on the hunger scale correlated positively and highly ($r = .375$, $p = .011$; see Figure 4). That is, the higher the ratings on the hunger scale, meaning that participants felt hungrier, the larger the pupils.

Therefore, the data do not only indicate that hungry participants showed larger pupil sizes than satiated ones, but that their individual feelings of hunger are correlated with this physiological measure.

4 DISCUSSION

In the present study we investigated whether a bodily drive like hunger leads to an attentional bias towards relevant (i.e., food) pictures. This was examined using measures of eye movements allowing an examination of early perceptual processes. Second, we aimed to

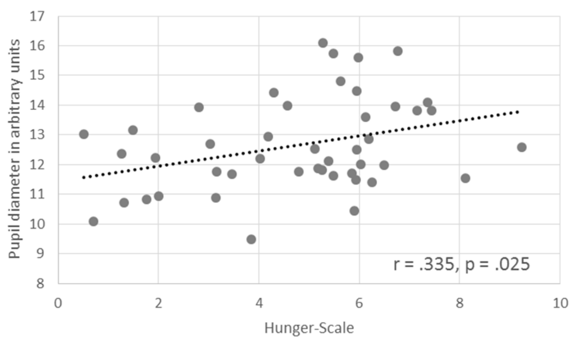

Figure 5: Correlation between pupil size and the ratings on the hunger-scale of Flint et al. (2000).

elucidate whether pupillometry is a valid measure for a sympathetic increase associated with hunger.

First of all, we derived at investigating differences between more and less hungry participants, as instructions and subjective reports confirmed. In addition, referring to overt performances in a classification task using food and household items as stimuli, there was no difference between hungry and satiated participants observable. Also the direction of the first fixation was unaffected by hunger as well as by the stimulus category.

Nevertheless, effects of hunger could be observed in more implicit gaze signals: The first fixation duration was longer on the right AOI for hungry compared to satiated ones. While all participants had fixated more often on household items, this effect was more pronounced for hungry participants. Hence, we observed an interaction of hunger and stimulus category. The results are now discussed in more detail.

Using the direction of the initial fixation we aimed at examining an early attentional bias towards food items for hungry participants and investigated the priority of a visual field. We found that most of the initial fixations hit the left AOI independent of the displayed stimulus configuration and participants' state of hunger. Thus, in completing the task participants followed normal reading direction and started at the left and later changed to the right AOI. This effect suggests that in the current set-up, the initial fixation direction indicates more a routine behaviour being less influenced by the bodily disposition of hunger and the stimulus category. Our results are in contrast to the study of Giel et al. (2011) who found that hungry participants initially fixated more often on food items. However, there are some important differences in the study design which might account for the different results. Giel et al. (2011) employed a free viewing paradigm without a specific task whereas we instructed the participants to classify whether the same category or different categories were presented in the visual fields. Furthermore, we instructed our participants to react as fast and as accurately as possible. This could have resulted in a more rigid deployment of practiced search techniques. Additionally, the distance between the two AOI was larger in our study. This difference might be important, as a greater distance between the centered fixation cross and the AOI might have impaired peripheral preprocessing of the stimuli.

Additionally, peripheral preprocessing may have been impaired by the similar depiction of food and non-food items on a white plate: This similar depiction and the fact that both stimuli were presented on a white plate, which may be a cue for food items, could have diminished the effects of peripheral perception on the direction of the initial fixation. More research in this field is needed to clarify the boundaries of peripheral preprocessing in hungry participants, when food and non-food items are presented while also controlling for stimulus characteristics of these two categories.

The results for first fixation durations showed that first fixations were longer when household items were shown compared to food items. This also becomes clear when considering that household items were presented on plates. It is obviously odd to see household items (like keys) presented on a white plate.

We found longer first fixation durations on the right AOI for hungry participants. When assuming that fixations towards the left in the current set-up reflect rather strategic processes, fixations towards the right might be regarded as more prone to user states.

A similar picture emerged for the amount of fixations on the AOIs: Overall, there were more fixations towards household items than towards food items supporting the assumption that household items presented on a plate are unfamiliar and therefore more difficult to process. But again, this effect was more pronounced for hungry subjects. This indicates that processing of non-food stimuli – the less relevant or more distracting category when being hungry - is impaired in hungry participants.

Our results are in accordance to former studies showing that hunger and the calorie content of food pictures also modulates the activation of early visual areas (Frank et al., 2010). The present study substantially extends these findings by showing that hunger might also affect effectiveness of visual search as indicated by longer fixation duration in hungry participants when food is presented in the paradigm. As we did not use a separate task with non-food stimuli only, potential expectation effects concerning food might have influenced the HH-categorization too. In addition to that, presenting household objects like keys on a plate might have increased the association with food for these objects as only food is usually presented or served on plates. Therefore, future research should consider using a more naturalistic display of household items.

Previous studies already confirmed the increase in sympathetic activation and decrease in parasympathetic activation of hunger (Chan et al., 2007). Given that pupil size is influenced by sympathetic activation (e.g. emotional arousal, Ehlers et al., 2016; Partala and Surakka, 2003), it was hypothesized that pupil dilation can be linked to hunger. The results of the present study indeed demonstrate the first time that the pupils of hungry participants are more dilated than the pupils of satiated ones. Moreover, the data show that pupil size and subjective hunger are positively correlated suggesting that this measure can also serve for diagnostic purposes. For user sensing, this means that pupil dilations have to be carefully interpreted with regard to potentially activating sources. That is, whether or not this method allows to discriminate between different sources of bodily arousal such as mental stress has to be further elucidated in future research. Besides, taking additional sources of bodily arousal into account, further studies should also examine whether user characteristics such as weight, height or psychological disorders such as eating disorders influence the results of hunger on sympathetic activation and attentional processing.

Hence, our study indicates that pupillometry is a feasible way to quantify bodily arousal as associated with hunger feelings. This method is therefore an innovative way to assess physiological processes in the context of bodily states.

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