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Visual attention to food cues in obesity: An eye-tracking study.

Doolan, K. J., Breslin, G., Hanna, D., Murphy, K., & Gallagher, A. M. (2014). Visual attention to food cues in obesity: An eye-tracking study. *Obesity*, 22(12), 2501-2507. <https://doi.org/10.1002/oby.20884>

Published in:
Obesity

Document Version:
Peer reviewed version

Queen's University Belfast - Research Portal:
[Link to publication record in Queen's University Belfast Research Portal](#)

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1 **Title: Visual attention to food cues in obesity: an eye-tracking study**

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8

9 **Keywords:** incentive sensitization; attentional bias; visual probe; energy density; hunger;
10 reward

11

12 **Running title:** Attentional bias to visual food cues in obesity

13

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21

22 **Abstract**

23 **Objective:** Based on the theory of incentive sensitization, the aim of this study was to
24 investigate differences in attentional processing of food-related visual cues between normal
25 weight and overweight/obese males and females.

26 **Design and Methods:** Twenty-six normal weight (14M, 12F) and twenty-six
27 overweight/obese (14M, 12F) adults completed a visual probe task and eye-tracking
28 paradigm. Reaction times and eye-movements to food and control images were collected
29 during both a fasted and fed condition in a counterbalanced design.

30 **Results:** Participants had greater visual attention towards high energy dense food images
31 compared to low energy dense food images regardless of hunger condition. This was most
32 pronounced in overweight/obese males who had significantly greater maintained attention
33 towards high energy dense food images as compared to their normal weight counterparts
34 however no between weight group differences were observed for female participants.

35
36 **Conclusions:** High energy dense food images appear to capture visual attention more
37 readily than low energy dense food images. Results also suggest the possibility of an altered
38 visual food cue-associated reward system in overweight/obese males. Attentional
39 processing of visual food cues may play a role in eating behaviours thus should be taken into
40 consideration as part of an integrated approach to curbing obesity.

41

42

43

44 **What is already known about this subject?**

- 45 • Research has demonstrated that exposure to food visual cues and the subsequent
46 activation of reward pathways in the brain may play a role in obesity.
- 47 • To date, a number of researchers have investigated attentional responses to food
48 cues in both normal weight and overweight/obese populations however results have
49 been conflicting.
- 50 • Despite eye-tracking being considered to be one of the most direct methods of
51 assessing attentional bias, studies that have been conducted to date using this
52 technique have only addressed differences in the attentional processing of visual
53 food cues between normal weight and overweight/obese individuals within female
54 populations.

55 **What this study adds**

- 56 • Results from the present study indicate that HED food images are more 'attention
57 grabbing' than LED food images.
- 58 • Findings also provide for the first time, evidence for a possible dysregulation of a
59 visual food cue-associated reward system in overweight/obese males
- 60 • This study highlights the need for future studies using eye-tracking as a direct
61 method of assessing visual attention to clarify the potential role of attentional bias
62 may have in the development and maintenance of obesity

63

64

65 **Introduction**

66 It has been suggested that the current 'obesogenic' environment is contributing greatly to
67 the worldwide obesity epidemic^{1,2}. This environment consists of palatable, energy dense
68 foods that are easily accessible and extensively marketed³. Research has demonstrated that
69 exposure to high energy dense (HED) food cues and the subsequent activation of reward
70 pathways in the brain may play a role in both the development and maintenance of
71 obesity^{4,5}. This concept stems from the theory of incentive sensitization⁶ which suggests
72 that modification of the dopaminergic reward systems in the brain results in increased
73 salience to related visual cues. As attentional bias to food cues is a potentially modifiable
74 factor⁷⁻¹⁰, it is of interest to further understand the potential role enhanced attention to
75 food visual stimuli may have on eating behaviours and food choices as part of an integrated
76 approach to addressing obesity.

77

78 To date, a number of researchers have investigated attentional responses to food cues in
79 normal weight¹¹⁻¹³ and overweight/obese populations^{4,14-18} however results have been
80 conflicting. For example, a study conducted by Nijs *et al.*¹⁴ using a modified Stroop test,
81 observed greater interference to food words in obese participants with higher levels of self-
82 reported food cravings as compared to their normal weight counterparts. In contrast
83 Loeber *et al.*¹⁵ used a visual probe task and found no difference in attentional bias to food
84 cues between normal weight and obese individuals. Such inconsistencies within attentional
85 processing research may be explained by the use of different methodological approaches
86 with previous studies using indirect methods, such as the modified Stroop test and visual
87 probe task that do not allow for the assessment of the direction of attentional bias¹⁶. More

88 recently, research has focused on the use of the more direct method using eye-tracking to
89 measure visual attention that overcomes the methodological issues associated with indirect
90 measures of attentional bias^{19,20}.

91

92 Eye-tracking is a non-invasive method of measuring visual gaze that provides a direct,
93 ecologically valid assessment of attentional bias^{21,22}. To date, this technique has been
94 employed in studies investigating attentional processing of visual food cues between normal
95 weight and overweight/obese females. Castellanos *et al.*⁴ combined eye-tracking with a
96 visual probe task to establish differences in attentional bias to food images in normal weight
97 and obese women in a fasted and fed condition. Both weight groups had increased visual
98 gaze towards food images compared to non-food images in the fasted state. In the satiated
99 condition, obese participants retained incentive salience to food cues. More recently
100 Werthmann *et al.*¹⁶ investigated differences in attentional bias for HED related food cues in
101 overweight females compared to normal weight females in a fed state. This study included
102 a visual probe task and recording of eye-movements and observed that overweight/obese
103 females initially directed attention towards food images compared to non-food images to a
104 greater extent than normal weight individuals but found no significant difference in
105 maintained visual attention.

106

107 Despite eye-tracking being considered as a direct method of assessing attentional bias^{21,22},
108 studies conducted to date using this technique have only addressed differences in
109 attentional processing of visual food cues between normal weight and overweight/obese
110 individuals within female populations^{4,16,17,18}. Male participants have been excluded from
111 these studies due to reported gender differences in eating style traits,^{18,23} behavioural and

112 neural responses to foods^{24,25} or to improve homogeneity^{4,17} therefore it is unclear whether
113 there are differences in attentional processing of visual food cues as directly assessed by
114 visual gaze between normal weight and overweight/obese individuals in a male population.

115

116 Several authors have reported that the energy content of visual food cues may play a role in
117 increased attention to food stimuli^{4,16,17}. In line with the theory of incentive sensitization,
118 these studies have suggested HED foods are considered to be more rewarding and as a
119 result HED food visual cues become more salient and receive greater selective attention.

120 HED foods are overtly represented within the visual environment through food advertising¹⁶
121 therefore it is of interest to further understand if certain individuals, in particular those who
122 are overweight/obese, have increased attention towards HED food stimuli.

123

124 The aim of this study was to extend previous research by investigating the impact of weight
125 status, satiation state and energy density content of food images on attentional processing
126 of visual food cues in females. For the first time, differences in attentional processing of
127 visual food stimuli between normal weight and overweight/obese males using a direct
128 assessment of visual gaze were examined. It was hypothesised that fasting would increase
129 attention to food cues and that overweight/obese individuals would maintain increased
130 attentional bias for food cues when satiated. Furthermore it was hypothesised that
131 participants would have greater attention to HED food images as compared to low energy
132 density (LED) related food images.

133

134

135

136 **Methods and procedures**

137 *Participants*

138 Participants were recruited through email and poster advertisements. The flow of
139 participants through the study protocol is presented in Figure 1. Eligible participants were
140 healthy males and females aged 18-65 years (mean 29.2 SD 10.7 years), with a body mass
141 index (BMI) of 18.5-34.9kg/m². Participants with a BMI between 18.5-24.9 kg/m² were
142 classified as normal weight and those with a BMI of 25-34.9 kg/m² were classified as
143 overweight/obese²⁶. Exclusion criteria (adapted from Nijs *et al.*¹⁸) were applied as follows:
144 spectacle wearers or presence of known ocular disease; tobacco users; taking any
145 medication that may influence eating behaviour; presence of any known chronic diseases
146 and participation within the past three months in an intervention aimed at losing weight.
147 Written informed consent was obtained from all participants.

148

149 *Study design*

150 The study design was modified from Castellanos *et al.*⁴. Participants attended on two study
151 days at least 5 days apart and completed the experimental task once in a fasted state and
152 once in a fed state. Participants were instructed to fast for a minimum of 8 hours before
153 both sessions and were randomly assigned to perform the experimental task in the fasted or
154 fed state at the first study session to prevent study order bias. Participants were contacted
155 before their study session to remind them to fast and on the day of the study session,
156 participants were asked by a researcher if they had adhered to this instruction with all
157 participants confirming they had. Participants' height was measured to the nearest
158 millimetre (mm) using a free standing stadiometer and weight measured to the nearest
159 kilogram (kg) using a digital scale. For the fasted trial, participants completed a visual

160 analogue scale (VAS) questionnaire²⁷ and then immediately undertook the experimental
161 task. The VAS questionnaire was completed to determine participants' self-reported feelings
162 of hunger and fullness. The scale was an anchored line of 100mm, with for example in
163 question one, 0mm equaling "Not at all hungry" and 100mm equaling "As hungry as I have
164 ever felt". For the fed trial, participants consumed a liquid meal (milkshake: 0.65kcal/ml,
165 61% carbohydrate, 21% protein, 18% fat) provided in an opaque glass, consumed through a
166 straw until further refills were declined and participants reported they could consume no
167 more. The volume of liquid meal consumed was recorded to the nearest millilitre and
168 hunger levels were assessed using VAS approximately twenty minutes after consumption.

169

170 *Experimental Task*

171

172 *Visual Probe Task*

173 Visual stimuli consisted of pairs of images containing 20 LED related foods and non-food
174 matches and 20 HED related foods and non-food matches⁴. HED related food images were
175 considered as those high in fat and/or sugar (e.g. chocolate, pizza), and LED related food
176 images were considered as those with a high water content and low in fat and/or sugar (e.g.
177 fruits, vegetables). Each food image was matched to a non-food image for size, complexity
178 and colour ensuring it was only the content (whether the stimuli was a food or non-food)
179 that differed between image pairs. Non-food images included items such as stationary and
180 tools.

181 The experimental task began with a central fixation cross shown for 1000ms, followed by
182 the image pairs for 2000ms. After each image pair, a dot probe replaced one of the previous
183 images, remaining until the participant made a manual response by pressing the

184 corresponding key on a computer keyboard. Participants were instructed to respond to the
185 probe as quickly as possible. Each image pair was shown twice in a random order with filler
186 images randomly interspersed to reduce monotony. Reaction time data from the visual
187 probe task was collected using E-prime software 2.0. Consistent with previous studies^{4,11,21},
188 incorrect responses, reaction times of less than 200ms or greater than 1500ms and reaction
189 times exceeding the mean individual reaction time of the participant plus or minus 3
190 standard deviations were excluded from subsequent analysis. Reaction time bias scores
191 were calculated by subtracting reaction times of congruent trials (probe replaced the food
192 image) from reaction times of the incongruent trials (probe replaced the non-food image).
193 Positive values indicate attention bias towards food images; negative values indicate
194 attention bias away from food images and towards non-food (control) images¹¹.

195

196 *Eye-Movement Data*

197 A head-mounted eye-tracker was used to collect eye-movement data during the visual
198 probe task. Prior to the beginning of the task, participant eye-movements were calibrated
199 using a 9-point calibration frame. Gaze fixation measurements were sampled every 16ms⁴.
200 Fixations were considered as (a) saccades that remained stable for ≥ 100 ms¹⁸ (b) the initial
201 fixation was initiated at least 100ms after image onset, as fixations < 100 ms may reflect
202 anticipatory eye-movements¹⁸ and (c) fixations that were directed to the left or right
203 image¹⁵. Eye-movement data was analysed using ASL Gaze Tracker software. Gaze fixations
204 that occurred outside of image pairs (e.g. on blank screen/not on the screen) were excluded
205 from data analysis. Two measures were obtained from gaze fixation data; gaze direction
206 bias and gaze duration bias^{4,18}. Gaze direction bias is considered as a measure of initial
207 attentional orientation, calculated using the number of trials in which the first fixation was

208 directed to a food image as a proportion of all trials in which the fixation was made towards
209 either the food or control image. A direction bias score >0.5 indicates attentional bias
210 towards food images; equal to 0.5 represents no bias and <0.5 reflects an orienting bias
211 towards control images. Gaze duration bias is considered as a measure of maintained
212 attention, calculated using the average gaze duration to a food image across all trials as a
213 proportion of the average gaze duration to all images (food and control). Similarly to gaze
214 direction bias scores, a duration bias score of >0.5 , 0.5 or <0.5 represents maintained
215 attention to food pictures, no bias and maintained attention to control images respectively.

216

217 *Statistical analyses*

218 Statistical analyses were conducted using the Statistical Package for the Social Sciences
219 software version 21. All data was considered to be normally distributed. Statistical analyses
220 were conducted firstly at a group level comparing normal weight vs. overweight/obese
221 participants and secondly, due to reported gender differences in eating style traits¹⁸, data
222 was split by gender for comparison between weight groups in males and females.
223 Independent *t*-tests were used to compare demographic characteristics (e.g. age) between
224 BMI categories. Self-reported hunger levels (measured using VAS) before and after liquid
225 meal consumption were compared using a mixed between-within analysis of variance
226 (ANOVA) with VAS score from the fasted trial and fed trial as within-subject variables and
227 weight group (normal weight vs. overweight/obese) as the between subject variable.
228 Analyses of reaction time and eye-movement data were also conducted using mixed-design
229 ANOVA with weight group as the between-subject factor and hunger condition (fasted vs.
230 fed), image type (food image vs. control image) and food image energy density content
231 (HED food image vs. LED food image) as within-subject factors. One sample *t*-tests were

232 used to compare reaction time bias scores to a test value of zero and food image direction
233 and duration bias scores to a test value of 0.5. An alpha level $p < 0.05$ was considered to
234 represent statistical significance throughout.

Commented [KD1]: Does it make sense to word the 2 difference values for the one sample t tests like this?

235

236 Results

237 Baseline characteristics

238 Participant demographics are summarised in Table 1. Both weight ($t(50) = -5.75, p < 0.001$)
239 and BMI ($t(50) = -9.82, p < 0.001$) were significantly different between the study groups
240 (normal weight vs. overweight/obese). Participants in the overweight/obese group were
241 significantly older compared to those in the normal weight group (mean 33.5 SD 12.9 years
242 vs. mean 24.9, SD 5.2 years respectively; $t(50) = -3.15, p = 0.003$). There was a main effect
243 of satiety condition, ($F(1, 50) = 108.8, p < 0.001$) with all participants reporting lower levels
244 of hunger following liquid meal consumption (mean subjective hunger ratings, were 60.3
245 (SD 21.5) mm when fed and 17.4 (SD 19.2) mm when fasted). There was no significant
246 difference in hunger levels or amount of liquid meal consumed between BMI groups ($F(1,$
247 $50) = 0.025, p = 0.874$).

248

249 Reaction time bias data

250 Mean reaction times and mean reaction time bias scores are given in Table 2. No significant
251 effects of BMI group or satiety condition were observed for reaction time bias scores. There
252 was a significant main effect for energy density in reaction time bias scores ($F(1, 50) = 5.15,$
253 $p = 0.028$) with all participants in a satiated condition having a greater attentional bias
254 towards HED food images (mean reaction time bias score 6.7, SD 43.6) as compared to LED
255 food images (mean reaction time bias score -11.5, SD 43.5) but this was not observed whilst

256 participants were in a fasted condition ($p>0.05$). One sample *t*-test analysis demonstrated
257 however that reaction time bias scores for HED and LED food images when satiated were
258 not significantly different from a test score of zero ($t(51) = 1.1, p=0.063$ and $t(51) = -1.9,$
259 $p=0.275$ respectively).

Commented [KD2]: Can I state that the results from the ANOVA were significant but when followed up with a one sample *t* test the values did not significantly differ from a score of zero?

260

261 *Gaze direction bias*

262 Gaze direction bias scores are presented in Table 3. There was a significant main effect of
263 energy density ($F(1, 50) = 14.64, p<0.001$) with all participants regardless of satiety
264 condition or BMI group demonstrating greater bias towards HED (mean 0.524, SD 0.05) as
265 compared to LED food images (mean 0.476, SD 0.05). One sample *t*-test analysis
266 demonstrated that participant direction bias scores for HED and LED food images were
267 significantly different from a test score of 0.5 ($t(51) = 3.9, p<0.001$ and $t(51) = -3.8, p<0.001$
268 respectively).

269

270 *Gaze duration bias*

271 A main effect for energy density (Table 3) was observed in gaze duration bias scores ($F(1,$
272 $50) = 14.44, p<0.001$) with all participants regardless of satiety condition or BMI group
273 attending to HED food images for a longer duration than LED food images (mean gaze
274 duration bias scores of 0.515 (SD 0.05) and 0.485 (SD 0.05) respectively). One sample *t*-tests
275 were conducted for HED and LED food duration bias scores and results demonstrated a
276 significant difference from a test score of 0.5 ($t(51) = 2.2, p=0.04$ and $t(51) = -2.2, p<0.04$
277 respectively).

278

279

280 *Males*

281 In terms of gaze direction bias scores, there was a significant main effect of energy density
282 ($F(1, 26) = 9.53, p=0.005$) with all males, regardless of BMI group or satiety condition,
283 demonstrating greater orienting bias towards HED (mean 0.526, SD 0.05) as compared to
284 LED food images (mean 0.473, SD 0.05).

285

286 All male participants demonstrated a significantly greater gaze duration bias towards HED
287 (mean 0.513, SD 0.053) as compared to LED food images (mean 0.491, SD 0.06), $F(1, 26) =$
288 $7.39, p=0.012$. There was also a statistically significant interaction between BMI group and
289 energy density ($F(1, 26) = 4.94, p=0.035$; see Figure 2a) with overweight/obese males
290 having a greater gaze duration bias towards HED food images (mean 0.523, SD 0.06)
291 compared to normal weight males (mean 0.502, SD 0.06). No effects for satiety condition
292 were observed in gaze duration bias scores.

293

294 *Females*

295 In terms of gaze direction bias scores, female participants had a significantly greater
296 orienting bias towards HED food images (mean 0.521, SD 0.04) as compared to LED food
297 images (mean 0.479, SD 0.05), $F(1, 22) = 4.87, p=0.038$.

298

299 Analysis of mean gaze duration bias scores in female participants demonstrated a significant
300 main effect for energy density. All females demonstrated a greater gaze duration bias
301 towards HED (mean 0.518, SD 0.05) compared to LED food images (mean 0.477, SD 0.05, F
302 $(1, 22) = 2.86, p=0.006$; see Figure 2b).

303

304 **Discussion**

305 The results from eye-movement data demonstrate that all participants had greater visual
306 attention to HED food images compared to LED related food images indicating increased
307 attentional bias towards HED visual food stimuli. These results support previous research
308 demonstrating that HED food images are more 'attention-grabbing' than LED food images⁴.
309 HED foods tend to be higher in fat and sugar that have been linked to greater stimulation of
310 reward pathways in the brain which may account for increased attentional bias towards
311 these visual stimuli^{25,28}.

312
313 Previous studies have failed to consider potential weight differences in the attentional
314 processing of visual food cues in a male population^{4,13,17,18}. Results from the current study
315 demonstrated that overweight/obese males had significantly greater maintained attentional
316 bias to HED food images compared to normal weight males. These findings are the first to
317 investigate and identify differences in attention to food stimuli using eye-tracking as a direct
318 assessment of visual attention between weight groups in adult males. Findings indicate
319 that greater attention to HED food cues may have a role in the development and
320 maintenance of obesity not only in females as demonstrated by previous research⁴, but also
321 in males. Future studies investigating attentional processing of food visual cues should
322 therefore include males and females.

323
324 In contrast to what was hypothesised, no differences between weight groups were observed
325 in regards to visual attention to food images in female participants however there appeared

326 to be a trend for overweight/obese females to have reduced attention to HED food images
327 as compared to their normal weight counterparts. The current results are in contrast to the
328 work of Castellanos *et al.*⁴ who reported that obese females had greater attention to food
329 images compared to normal weight females as measured by eye-tracking data. Other
330 researchers however have suggested that females, in particular overweight females, may
331 employ cognitive strategies to reduce attentional allocation to visual food cues as a means
332 of preventing disinhibited food intake^{16,18}. This attentional 'avoidance strategy' may in part
333 explain findings in the current study and highlights the importance of avoiding a 'one size
334 fits all approach' to applying conclusions drawn from investigating attentional processing in
335 obese females to those who are overweight.

336

337 No effect for satiety was observed in any attentional processing measures in the present
338 study. This was in contrast to the hypothesis that attention to visual food cues would be
339 moderated by satiety condition and evidence presented in previous studies that
340 demonstrated an increase in attention to food images⁴ and food words²⁹ in a fasted
341 condition. One reason for the inconsistency in findings may have been the use of a liquid
342 meal to induce satiety. Although all participants confirmed they had adhered to instructions
343 to fast prior to both study sessions and reported significantly reduced feelings of hunger
344 following consumption of the liquid meal, it is possible participants may have been less
345 hungry than they indicated on visual analogue scales prior to and following study meal
346 consumption.

347

348 Reaction time data from the visual probe task did not yield any between-weight group
349 differences. These results are similar to those observed by Castellanos *et al.*⁴ who failed to
350 observe any statistically significant differences between weight groups (normal weight
351 versus obese women) in reaction time data from a visual probe task however did report a
352 main effect of weight group in attentional bias scores obtained from eye-tracking data.
353 These results may in part be explained by issues in interpreting results obtained from a
354 visual probe task. Reaction time data is usually considered to be an indirect measure of
355 attention allocation at stimuli presentation offset however it has been suggested that
356 participants may 'shift' their attention from one stimulus to another in tasks with longer
357 stimuli presentation times e.g. >500ms³⁰. It may be useful for future studies to employ the
358 recording of eye-movements as a more direct method to provide information on attentional
359 engagement and disengagement to visual food-related cues.

360

361 The present study had some limitations that should be taken into consideration. Firstly,
362 although results from the VAS questionnaire suggested participants felt full following
363 consumption of the liquid meal, it may not have been fully effective in inducing satiety.
364 Secondly both overweight and obese individuals were included, perhaps future studies
365 could better account for BMI differences by recruiting equal numbers of normal weight,
366 overweight and obese individuals to allow for direct comparison of potential differences
367 between BMI categories and attention to visual food cues.

368

369 Despite these limitations, the present study has several strengths. The use of both direct
370 (eye-tracking) and indirect (visual probe task) methods were used to assess attentional bias

371 allowing for direction and duration of initial and maintained visual attention to be
372 measured. As previously discussed, it has been suggested using a direct method or a
373 combination of a direct and indirect method may overcome some of the methodological
374 issues encountered using an indirect measure alone such as the interpretation of the
375 direction of allocated attention³¹. The inclusion of male participants was a novel aspect of
376 this research and to the author's knowledge is the first study to date to identify greater
377 attentional bias to HED food images using a direct method of assessment in
378 overweight/obese males as compared to their normal weight counterparts. Finally, the
379 inclusion of both HED and LED food cues allowed for comparison of energy density content
380 of food images which to date has only been investigated in a limited number of studies
381 using eye-tracking as a direct measure of visual attention in an overweight/obese
382 population^{4,17}.

383 Results from the present study indicate that HED food images are more 'attention grabbing'
384 than LED food images. The findings also provide, for the first time, evidence for a possible
385 dysregulation of a visual food cue-associated reward system in overweight/obese males,
386 with this weight group displaying greater attentional bias towards HED food images than
387 their normal weight counterparts. Future studies using eye-tracking as a direct method of
388 assessing visual attention are required to clarify the potential role of attentional bias in the
389 development and maintenance of obesity.

390

391 **Conflicts of interest:** The authors declare no conflicts of interest

392

393 **Funding:** PhD sponsorship was obtained from the Department for Employment and
394 Learning, Northern Ireland. Eye tracking equipment was funded by the Department for
395 Employment and Learning Research Capital Investment Fund.

396

397 **Acknowledgements:** The authors would like to acknowledge Dr Sinead Smyth for the design
398 of the visual probe task and extend their thanks to those who took part in the study.

399

400 **Author contributions:** AMG and GB designed the study and KJD recruited participants and
401 conducted the research. KM assisted with participant recruitment, data collection and
402 entry. DH advised on statistical analyses. KJD analysed the data and prepared the first draft
403 of the manuscript. AMG, GB and DH critically reviewed the manuscript and approved the
404 final version. AMG led the research and finalised the manuscript.

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586 **Table 1.** Baseline characteristics and subjective hunger rating scores of study participants.

	Normal weight		Overweight/obese		<i>P</i>
	(n26)		(n26)		
	Mean	SD	Mean	SD	
Baseline characteristics^a					
Age (years)	24.9	5.2	33.5	12.9	0.003
Height (cm)	173.5	11.2	173.3	9.2	0.949
Weight (kg)	67.6	12.0	88.3	13.9	<0.001
BMI(kg/m ²)	22.2	1.9	29.3	3.2	<0.001
Study meal (kJ)	2319.1	302.3	2600.3	340.0	0.454
Subjective hunger rating (VAS)^b					
Fasted*	61.4	21.8	59.2	21.6	
Fed	19.2	21.5	15.7	16.7	0.874

587

588 Data are means , SD unless otherwise noted.

589 Abbreviations: BMI, body mass index. VAS, visual analogue scale measured in mms.
590

591 *P*<0.05 indicates differences between weight groups. ^aIndependent *t*-test. ^bMixed design ANOVA.
592

593 *Significant difference between fasted and fed VAS scores in all participants regardless of BMI category.
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597 **Table 2** Mean reaction time measures for normal weight and overweight/obese participants in
 598 fasted and fed conditions.

	Normal weight (n26)		Overweight/obese (n26)	
<i>RTs (ms)</i>	Mean	SD	Mean	SD
Fed HED incongruent	541.5	71.9	537.8	91.6
Fed HED congruent	531.5	47.9	534.4	83.5
Fed LED incongruent	524.5	59.5	535.3	84.9
Fed LED congruent	541.2	70.8	541.6	79.6
Fasted HED incongruent	553.9	116.2	546.7	89.0
Fasted HED congruent	539.6	94.3	556.7	95.2
Fasted LED incongruent	540.2	107.3	545.6	85.0
Fasted LED congruent	538.9	105.9	552.1	91.3
<i>RT bias score</i>				
Fed HED	9.9	48.9	3.4	37.9
Fed LED	-16.7	49.0	-6.3	37.6
Fasted HED	14.3	44.5	-10.0	36.2
Fasted LED	1.2	56.2	-6.5	55.4

599

60 Abbreviations: RT, reaction time; HED, high energy density; LED, low energy density.

60 Visual probe task: Incongruent – probe replaces control image, congruent – probe replaces food image.

60

603 **Table 3** Mean attention bias measures of normal weight and overweight/obese participants in fasted
 604 and fed conditions.

605

	Normal Weight (n26)		Overweight/obese (n26)	
	Mean	SD	Mean	SD
<i>Gaze direction bias</i>				
Fed HED	0.513	0.06	0.522	0.07
Fed LED	0.487	0.06	0.477	0.07
Fasted HED	0.525	0.06	0.533	0.05
Fasted LED	0.477	0.06	0.464	0.05
<i>Gaze duration time (ms)</i>				
Fed HED food	441.2	136.3	450.0	120.4
Fed HED control	419.1	117.5	431.2	93.1
Fed LED food	424.7	135.9	392.2	71.9
Fed LED control	430.6	114.6	438.8	109.9
Fasted HED food	415.3	153.5	433.3	143.9
Fasted HED control	371.4	134.7	413.1	110.9
Fasted LED food	391.1	166.3	405.6	112.6
Fasted LED control	357.2	117.6	415.9	114.5
<i>Gaze duration bias</i>				
Fed HED	0.504	0.08	0.519	0.07
Fed LED	0.477	0.07	0.478	0.06
Fasted HED	0.525	0.08	0.512	0.05
Fasted LED	0.489	0.11	0.495	0.04

Abbreviations: HED, high energy density; LED, low energy density.

Figure 1 Study protocol and participant flow through study.

Abbreviations: VAS, visual analogue scale. *Participants were required to fast for a minimum of 8 hours before each trial day and randomly assigned to trial order on first visit. +Eye tracking paradigm – combination of visual probe task and eye tracking.

Figure 2 Mean gaze duration bias scores as a function of weight group (normal weight vs. overweight/obese) and food image energy density content (high energy density vs. low energy density) for (a) males and (b) females.

Gaze duration bias score >0.5 , 0.5 or <0.5 represents maintained attention to food related images, no bias and maintained attention to non-food (control pictures) related images respectively. Mixed design ANOVA: weight group (normal weight vs. overweight/obese) as between-subject factor; gaze duration bias scores (high energy density vs. low energy density) as within-subject factor. Different letters represent statistically significant differences.