

Discomfort from urban scenes: metabolic consequences

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- Certain statistical properties of images are responsible for visual discomfort
- These properties are prevalent in images of the modern urban environment
- The discomfort is associated with inefficient neural processing and a large metabolic demand

1 Abstract

2 Scenes from nature share in common certain statistical properties. Images with
3 these properties can be processed efficiently by the human brain. Patterns with
4 unnatural statistical properties are uncomfortable to look at, and are processed
5 inefficiently, according to computational models of the visual cortex. Consistent
6 with such putative computational inefficiency, uncomfortable images have been
7 demonstrated to elicit a large haemodynamic response in the visual cortex,
8 particularly so in individuals who are predisposed to discomfort. In a succession
9 of five small-scale studies, we show that these considerations may be important
10 in the design of the modern urban environment. In two studies we show that
11 images from the urban environment are uncomfortable to the extent that their
12 statistical properties depart from those of scenes from nature. In a third study
13 we measure the haemodynamic response to images of buildings computed as
14 having unnatural or natural statistical properties, and show that in posterior
15 brain regions the images with unnatural statistical properties (often judged
16 uncomfortable) elicit a haemodynamic response that is larger than for images
17 with more natural properties. In two further studies we show that judgments of
18 discomfort from real scenes (both shrubbery and buildings) are similar to those
19 from images of the scenes. We conclude that the unnatural scenes in the
20 modern urban environment are sometimes uncomfortable and place excessive
21 demands on the neural computation involved in vision, with consequences for
22 brain metabolism, and possibly also for health.

23 Scenes from nature have in common the characteristic that their gross aspects have
24 a higher contrast than the fine detail. In mathematical terms, the Fourier amplitude
25 spectrum decreases approximately as the reciprocal of the spatial frequency, i.e.
26 approximately as $1/f$ (Field, 1987). The neural computation involved in sight is well-
27 designed to take advantage of the $1/f$ characteristic (Field, 1987, 1994; Geisler 2008).

28

29 Images with unnatural amplitude spectra are judged uncomfortable to look at
30 (Fernandez & Wilkins, 2008; Juricevic, Land, Wilkins, & Webster, 2010; Penacchio &
31 Wilkins, 2015b). Such uncomfortable stimuli include the patterns of repetitive stripes
32 that are commonplace in the modern urban environment. Computational models of
33 the visual cortex by Hibbard & O'Hare (2014) and Penacchio, Otazu, Wilkins & Harris
34 (2016) suggest that such uncomfortable repetitive patterns render the firing of
35 cortical neurons less "sparse", increasing the overall firing rate, with the potential of
36 raising metabolism in consequence. Indeed, there is growing evidence for a raised
37 metabolism in so far as uncomfortable stimuli trigger a strong haemodynamic
38 response in the visual cortex. Huang, Cooper, Satana, Kaufman & Cao (2003) used
39 functional magnetic resonance imaging (fMRI) and measured the blood oxygen level
40 dependent (BOLD) response to achromatic gratings with a range of spatial
41 frequencies. Contrast sensitivity is maximal at mid spatial frequencies and Huang et
42 al showed that high contrast gratings with mid spatial frequency (which are
43 uncomfortable) gave the largest BOLD response. Haigh *et al.* (2013) used near
44 infrared spectroscopy (NIRS) over the visual cortex and measured the
45 haemodynamic response to coloured gratings. They found that coloured patterns of

46 stripes gave a larger oxyhaemoglobin response if they had large differences in their
47 component colours and were therefore uncomfortable to view.

48

49 Individuals differ in susceptibility to visual discomfort, and those individuals who are
50 relatively susceptible show a larger haemodynamic response than those who are less
51 so. This has been demonstrated in several studies involving patients with migraine
52 but also those without. Thus Huang et al. (2003) demonstrated that patients with
53 migraine report both discomfort and perceptual distortion when viewing gratings,
54 and show an abnormally large BOLD response to such stimuli. Martín et al. (2011)
55 compared 19 patients with migraine and 19 controls. Patients with migraine had a
56 larger number of activated occipital voxels in response to lights than did controls.
57 Cucchiara, Datta, Aguirre, Idoko, and Detre (2014) found that in migraine patients
58 who experienced aura the number of symptoms of discomfort they reported by
59 questionnaire correlated with the amplitude of the BOLD response to visual
60 stimulation.

61

62 Although the studies reviewed in the above paragraph concerned patients with
63 migraine, the relationship between discomfort and the size of the haemodynamic
64 response occurs independently of this diagnosis. Thus, Alvarez-Linera et al. (2006)
65 compared 20 photophobic patients with 20 controls who viewed a light source at
66 various intensities. There was a direct relationship between stimulus intensity and
67 the size of the BOLD response, and the response was larger in the photophobic
68 individuals. Finally Bargary, Furlan, Raynham, Barbur & Smith (2015) compared
69 normal participants with high and low thresholds for discomfort glare while they

70 identified the orientation of a Landolt C surrounded by peripheral sources of glare.
71 The group that was sensitive to discomfort glare had a larger BOLD response
72 localized at three discrete bilateral cortical locations: in the cunej, the lingual gyri
73 and in the superior parietal lobules. In conclusion, both in terms of the visual stimuli
74 and in terms of the people they affect, uncomfortable visual stimuli are associated
75 with a large haemodynamic response.

76

77 The visual stimuli that are uncomfortable can be quantified mathematically. As
78 shown by Fernandez & Wilkins (2008) and Penacchio & Wilkins (2015) they differ
79 from natural images in having an excess contrast energy at mid-range spatial
80 frequencies. The excess is relative to the energy expected on the basis of the
81 reciprocal relationship between Fourier amplitude and spatial frequency typical of
82 natural scenes ($1/f$). This characteristic is common in images from the urban
83 environment, and it is this visual aspect of the environment that we explore with a
84 series of five small-scale studies.

85

86 In the first two studies we show that photographs of certain buildings are
87 consistently rated as uncomfortable and have an excess of energy at mid spatial
88 frequencies relative to that expected from $1/f$. (Spatial frequency refers here to the
89 spatial repetition of contours on the retina and is therefore determined both by the
90 size of the pattern and the distance from which it is viewed.) In a third study we
91 show that observation of photographs with the statistical properties of unnatural
92 images elicits a larger haemodynamic response than for other images, consistent
93 with inefficient neural processing of unnatural and uncomfortable scenes. In two

94 further studies we show that photographs of scenes are a good surrogate for the
95 scenes themselves: the ratings observers make when looking at buildings or trees
96 and shrubs correlate strongly with those made when observing photographs of the
97 same scenes. The implication of these studies is that the design of the urban
98 environment is such as to render the neural computation involved in vision more
99 complex than it needs to be, with consequences for brain metabolism.

100 **Studies 1 and 2: Images of buildings**

101 **Procedure**

102 Un-posed images of urban scenes were obtained by the simple expedient of standing
103 at the side of a curb and aiming a camera across the street, angled so as to capture
104 as much as possible of the facade of the building opposite from a distance of 5-12m.
105 A Sony α -390 DSLR camera (without a zoom) was used and the viewing angle of the
106 camera was estimated from technical literature to be about 50 degrees. The images
107 were 960 pixels wide by 720 pixels high. Figure 1 shows maps of the locations where
108 the photographs were obtained, and Figure 2 a sample of 25 such images.

109 **INSERT FIGURES 1 AND 2 ABOUT HERE**

110 The images were divided into two sets, one set for each study, each set consisting of
111 74 different photographs presented in random order on the 344mm x 194 mm
112 screen of an Acer Aspire 5734Z laptop computer from a viewing distance of 0.6m, at
113 which distance they were 18 degrees high. Each image was presented until the
114 observer had given a rating and they were encouraged to do so within 10s.
115 Observers were asked to rate the images on a 7-point Likert scale with 1 labelled
116 "Very Comfortable" and 7 labelled "Very Uncomfortable".

117 **Participants**

118 Students at the University of Essex (12 males and 8 females aged 19 - 28) observed
119 each of the images and gave a rating. Ten different students took part in Study 1 and
120 10 in Study 2, which was a replication.

121

122 **Results**

123 The images differed significantly with respect to the ratings they received (Study 1:
124 $F(73, 657) = 3.00, p < .001, \eta^2 = .25$; Study 2: $F(73, 657) = 6.39, p < .001, \eta^2 = .41$).
125 Cronbach's alpha between raters was 0.67 in Study 1 and 0.84 ("good") in Study 2.

126 **Image analyses**

127 The images were analysed using the algorithm described by Penacchio & Wilkins
128 (2015). In their paper the studies are numbered 4 and 5. The algorithm measured
129 how closely each image approximated a natural image in respect of the shape of the
130 two-dimensional Fourier transform. In images from the natural world the amplitude
131 of the spectrum decreases with increasing spatial frequency approximately as $1/f$, so
132 that on log-log coordinates the spectrum approximates a cone in shape, with a slope
133 of -1. By varying the height of the cone, the algorithm obtained the best fit to the
134 Fourier transform of each image and weighted the residuals by a contrast sensitivity
135 function sourced from the literature, see Figure 3. The monitors were not gamma-
136 corrected, but such correction typically affected the slope of the spectral power
137 distribution by less than 2%. The contrast sensitivity function had a peak at 7
138 cycles/degree and was reduced to 78% of its peak value at spatial frequencies of 3.5
139 and 14 degrees, so variation in spatial frequency over a factor of about two, such as
140 occurred with the variation in viewing angle was of little consequence. The sum of
141 the weighted residuals correlated 0.60 with the ratings of discomfort from images
142 used in Study 1 and 0.53 with those in Study 2. In other words, in both studies the
143 algorithm explained more than 25% of the variance in the judgments of discomfort:
144 images that best approximated the cone were rated as most comfortable. Altering

145 the shape of the cone so as to accommodate the orientation anisotropy in images
146 made little difference to the ability of the model to predict discomfort, see
147 Penacchio & Wilkins (2015).

148

149 In the next experiment participants observed a subset of the images of buildings
150 while the cortical haemodynamic response was measured.

151

INSERT FIGURE 3 ABOUT HERE

152 **Study 3: Haemodynamic response to images of buildings**

153 **Participants.**

154 Twenty-six volunteers from the general population and from the University of Essex
155 served as participants. There were 4 males and 22 females, aged 18 – 53 (M = 26.4,
156 SD = 11.6)

157 **Stimuli and Apparatus.**

158 Using the algorithm from Penacchio & Wilkins (2015), the residual score for each of
159 the 148 images in Studies 1 and 2 was calculated and the images were divided about
160 the median score into two groups, 10 images with high residuals (median rank 32.5,
161 range 2-46) and 10 with low (median rank 108, range 71-125). As might be expected,
162 the images with high residuals were largely those judged to be uncomfortable, and
163 the images with low residuals were largely those judged comfortable. Nevertheless,
164 the segregation of images was on the basis of their statistical structure and was
165 therefore entirely objective.

166

167 The stimuli were presented on an UltraSharp 2408WFT 24" LCD monitor (60Hz
168 refresh rate) resolution 1920 x 1200. At the viewing distance of 0.7m the height of
169 the screen subtended 28.5 degrees. At the 50% brightness level used, the white
170 screen had a luminance of 101cd.m⁻².

171 **NIRS procedure.**

172 The cortical haemodynamic responses to each image were measured using near
173 infrared spectroscopy (NIRS). An 8-channel NIRS system was used (MK II; Artinis
174 Medical Systems BV, Zetten, The Netherlands). The optode placement for the
175 posterior channels included two receivers and six transmitters. The optodes for the
176 receivers were placed 30mm from either side of the midline 20mm above the inion.
177 For the left hemisphere, three transmitters were placed 35mm from the receiver,
178 above, to the left and obliquely at 45°. The symmetrically equivalent placement was
179 used for the right hemisphere. The frontal channels included two receivers and two
180 transmitters, in which the receivers covered positions FP1 and FP2 of the 10-20
181 system of electrode placement. Both transmitters were placed 35mm above their
182 respective receiver. This was a close replication of the configurations used by Haigh
183 et al. (2013).

184

185 The participants were asked simply to observe the images whilst keeping movement
186 to a minimum. A PowerPoint slideshow presented each stimulus for 16 seconds in a
187 fixed random order. Grey slides were used to separate the stimuli, and the inter-
188 stimulus intervals ranged in duration at random between 27 and 36 seconds.

189 **Data analysis**

190 To calculate the oxygenated haemoglobin concentration, a differential path length
191 factor (DPF) of 6.26 was used (Duncan et al., 1996). The raw signal was filtered with a
192 running median of 31 samples to remove cardiac artefacts. The detrend function in
193 MATLAB© was applied to remove any systematic drift in the signal. The
194 deoxyhaemoglobin signals were small relative to the oxyhaemoglobin signals. They
195 were negatively correlated, and significantly so ($r(23) = -.57, p < .01$). For this reason
196 only the oxyhaemoglobin responses were used in the subsequent analyses, following
197 Haigh et al. (2013).

198 The haemodynamic response amplitude was measured in terms of the difference
199 between the average of the signal during the last 10s of stimulus presentation and
200 the average 10s before stimulus onset. Some channels did not record a good signal,
201 often because hair obscured the optodes. Channels were therefore accepted for
202 analysis only if the amplitude of the haemodynamic response was greater than the
203 standard deviation of the signal during baseline, following Haigh et al. (2013).

204 **Results**

205 Twenty-five participants had at least one acceptable posterior channel (the average
206 number of acceptable channels per participant was 4.4). The signal was stronger in
207 posterior than frontal channels. Indeed in only five of the 25 participants were the
208 data from frontal channels acceptable. In these five participants the overall
209 amplitude for frontal channels ($M = 0.10\mu\text{M}, SD = 0.10$) was smaller than for
210 posterior channels ($M = 0.35\mu\text{M}, SD = 0.27$), though not significantly so because of
211 the small numbers, $t(4) = 2.06, p = .108, d = 1.3$.

212

213 The effects of the visual stimuli were analysed only for the posterior channels. The
214 average amplitude for all such channels for each participant was obtained, separated
215 by image category. Figure 4 and Table 1 show, the residual score from the model by
216 Penacchio & Wilkins (2015), the discomfort rating (from Studies 1 and 2), and the
217 average amplitude of the oxyhaemoglobin response across participants.

218

INSERT FIGURE 4 AND TABLE 1 ABOUT HERE

219 A repeated-measures ANOVA with image category as main effect revealed that
220 images with high residual scores induced a significantly larger haemodynamic
221 response in the occipital areas, mean $0.40\mu\text{M}$ (SD 0.29), compared to images with
222 low residuals, mean $0.28\mu\text{M}$ (SD 0.17), $F(1, 24) = 4.73$, $p < .05$, $\text{MSE} = 0.04$, $\eta^2 = 0.17$.
223 Figure 5 shows the average oxyhaemoglobin response for images with high and
224 images with low residual scores.

225

INSERT FIGURE 5 ABOUT HERE

226 The above analysis separated images on the basis of residuals, however it was also
227 important to separate images by discomfort rating. This is because some images
228 might have high residuals yet low discomfort rating (and vice versa), and indeed
229 when separating images by perceived discomfort (as assessed in Studies 1 and 2)
230 four images were re-categorised (relative to the previous grouping). Again, a
231 repeated-measures ANOVA with image category as main effect was conducted. The
232 results showed revealed that uncomfortable images, mean $0.40\mu\text{M}$ (SD = 0.28)
233 induced a significantly larger haemodynamic response in the occipital areas
234 compared to comfortable images mean $0.29\mu\text{M}$ (SD = 0.19), $F(1, 24) = 5.40$, $p < .05$,
235 $\text{MSE} = 0.29$, $\eta^2 = 0.18$.

236 **Interim Discussion**

237 Images of building frontages with a high residual score gave rise to a haemodynamic
238 response of greater amplitude than did those images with a low score. When the
239 images were separated according to discomfort rating, the greater amplitude was
240 induced by uncomfortable images. These findings are consistent with other
241 evidence reviewed earlier that, in general, uncomfortable visual stimuli are
242 associated with a large haemodynamic response. The result demonstrates that
243 images from the modern urban environment are sufficiently un-natural (and
244 uncomfortable) to give a large haemodynamic response and that this response can
245 be predicted quite objectively from the statistical properties of the image. A
246 relatively large haemodynamic response is suggestive of a relatively large metabolic
247 load in the occipital areas and therefore consistent with the behaviour of
248 computational models of the visual cortex that indicate a less sparse and stronger
249 neural response to stimuli that are uncomfortable. It has been suggested that the
250 discomfort is a homeostatic response that acts to restore normal metabolism
251 (Wilkins, 2015).

252 The fact that certain images of buildings are rated as uncomfortable and give rise to
253 a large haemodynamic response suggests that there are aspects of the design of the
254 modern urban environment that may be sub-optimal. Before such an inference can
255 be made, however, it is necessary to demonstrate that photographs are an
256 appropriate surrogate for real scenes in this respect. To do so, we asked observers
257 to rate visual comfort from real scenes and, later, photographs of those scenes.

258 **Ratings of real scenes and photographs.**

259 **Study 4**

260 **Procedure**

261 Eleven students from the University of Essex, aged 20-24, two with corrected vision,
262 acted as participants. The experimenter took the students on a walk around the
263 campus and asked the participant to stand at pre-arranged locations and directed
264 their gaze towards a particular view. The participants were required to rate the view
265 as to how “comfortable the scene was to look at” on an 11-point Likert scale, from -5
266 “very uncomfortable” through 0 (neutral) to +5 “very comfortable”. The participants
267 experienced the viewpoints in different orders. Ten “natural” views comprising
268 grass, shrubs and trees and 10 views of university buildings were presented in an
269 order that avoided successive presentation of more than two views within the two
270 above categories. Figure 6 shows examples of the scenes.

271 **INSERT FIGURE 6 ABOUT HERE**

272 At the end of the presentation the participants sat in front of the 15”screen of a
273 laptop computer, resolution 1440x900 pixels. At the viewing distance of about 0.5m,
274 the screen subtended 22 degrees vertically. Colour photographs of the 20 scenes
275 taken with a Canon PowerShot SX530 camera with an estimated 40degree field of
276 view (vertical) were presented for 16s on the screen in a fixed random order using
277 PowerPoint, and the participant was asked to rate the photographs on the same 11-
278 point Likert scale.

279

280 **Results**

281 There were no significant differences in mean ratings for the views and for the
282 photographs. The correlation between the ratings of a view and of its photograph
283 was $r = .89$, $p < .001$, suggesting that photographs induced similar levels of
284 (dis)comfort relative to the real scene. There was a good consistency between
285 observers: the average correlation between an individual observer's ratings and the
286 mean rating (and standard deviation) for the group was 0.79 (0.18) for views and
287 0.72 (0.14) for photographs. The ratings differed significantly between buildings , -
288 0.77 (1.44) and shrubbery, 2.38 (1.25), $t(9) = 9.84$, $p < .001$, $d = 2.3$. Separating the
289 images by category revealed that there was a significant correlation between a scene
290 and its photograph for buildings, $r = .75$, $p < .05$, but not for grass shrubs and trees, r
291 $= .58$, $p = .078$.

292 **Study 5 (Replication)**

293 The procedure was the same as that for Study 4 except that 10 different students
294 (six females and four males) of similar age (average 22 years) served as participants,
295 and the photographs were presented on the 21.5" screen of a laptop computer with
296 a resolution of 1920x1200 pixels. At the viewing distance of about 50cm the screen
297 subtended 23 degrees (vertical).

298

299 **Results**

300 As before, there were no significant differences in mean ratings for the views and for
301 the photographs, and the ratings were similarly consistent. Again, there was a strong
302 correlation between the mean ratings of a scene and of its photograph, $r = 0.75$, $p <$

303 .05. The mean ratings differed significantly between buildings -0.6 (1.50) and
304 shrubbery, 1.27 (1.26), $t(9) = 5.95$, $p < .001$, $d = 1.4$. Again, separating the images by
305 category revealed that there was a significant correlation between a scene and its
306 photograph for buildings, $r = .74$, $p < .05$, but not for grass, shrubs and trees, $r = .40$,
307 $p = .253$.

308

309 **Discussion**

310 We have shown that images of the modern urban environment are sometimes
311 uncomfortable and that this discomfort can be predicted from the unnatural
312 statistical properties of the image. We have demonstrated that images of buildings
313 with unnatural statistical properties are associated with a relatively large
314 haemodynamic response in the visual cortex, as is the case with other
315 uncomfortable visual stimuli. The larger haemodynamic response is consistent with
316 inefficient neural processing and with a greater metabolic load in consequence. We
317 have shown that views of buildings are rated as comfortable or uncomfortable in
318 much the same way as photographs of those views (notwithstanding the differences
319 in viewing angle) and thereby demonstrated that our findings have implications for
320 the design of the urban environment. In essence, the repetitive patterns in modern
321 architecture are unnatural, and in consequence they give rise to discomfort and a
322 higher metabolic demand on the visual cortex, consistent with neural processing that
323 may be relatively inefficient.

324

325 It might be argued that the present findings are secondary to effects of emotional
326 valence for example, the student attitude to the buildings in their university in
327 Studies 4 and 5 cannot easily be separated from their more general attitude to the
328 university as an institution. However, these effects cannot explain the results of
329 Experiments 1 and 2 and 3 in which the images of buildings were likely to have been
330 unfamiliar to all participants. In these experiments there was nothing to indicate that
331 the uncomfortable images were attended to any differently from those that were
332 more comfortable.

333

334 It is possible that some of the effects are attentional and arise because discomfort
335 attracts attention to or deflects it from an image. They may also be emotional in so
336 far as discomfort may give rise to an emotional response. This is of particular
337 relevance in Study 3 because attention and emotion are known to affect the
338 haemodynamic response, e.g. Henson & Mouchlianitis (2007). We measured the
339 response from posterior head regions and therefore from superficial layers of the
340 visual cortex. fMRI studies have shown strong attentional effects on the
341 haemodynamic responses of human primary visual cortex (e.g. Ghandi et al., 1999).
342 Although attention and emotion may have mediated the effects of image structure
343 on the amplitude of the haemodynamic responses observed in Study 3, it is likely to
344 be because of the discomfort, given the findings of our other studies, and the
345 convergence in the literature reviewed in the introduction.

346

347 Studies of aesthetics in urban design (Nasar, 1994), have already appreciated the
348 role of natural features (Sullivan & Lovell, 2006) and tools have been developed for

349 improving the aesthetics of urban streetscapes (Gjerde, 2011). Visual discomfort has
350 been discussed from the point of view of lighting design (Steemers, 1994) but until
351 recently it has not been possible to find a numerical expression for discomfort from
352 visual aspects of building structure. Discomfort can be predicted from simple
353 mathematical properties of the visual image (Penacchio & Wilkins, 2015), and here
354 we show that these properties are of importance for brain metabolism.

355

356 Some of the beneficial effects of green exercise (Pretty, Griffin, & Sellens, 2004;
357 Pretty, Peacock, Sellens, & Griffin, 2005) may arise because natural scenery avoids
358 the repetitive patterns common in the urban environment.

359

360

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427

428 Table 1. Experiment 3: residual score, discomfort ratings and average amplitude of
429 the oxyhaemoglobin response in order of stimulus presentation.

430

Image order	Residual score (x10 ¹¹)	Discomfort ratings	Amplitude ΔHbO_2
1	4.21	3.8	0.16
2	9.62	4.6	0.47
3	2.19	5.7	0.36
4	3.30	3.6	0.54
5	1.98	3.3	0.34
6	2.29	3.7	0.25
7	6.61	4.0	0.40
8	1.62	3.5	0.08
9	0.64	3.0	0.17
10	4.30	3.9	0.33
11	1.00	3.2	0.43
12	2.08	3.2	0.53
13	6.75	4.3	0.25
14	4.25	3.0	0.34
15	2.35	4.3	0.50
16	5.32	3.7	0.39
17	2.16	3.2	0.25
18	2.25	3.2	0.22
19	5.77	4.3	0.65
20	1.92	2.9	0.17

431

432

433 Figure Legends

434

435 Figure 1. Locations of buildings photographed. Top: London; Left centre:

436 Birmingham; Right centre: Norwich; Bottom left: Ipswich; Bottom right: Cambridge

437

438 Figure 2. Thumbnails of the first 25 images presented in Study 1.

439

440 Figure 3. Schematics of the computational metric of discomfort defined in Penacchio

441 and Wilkins 2015. (a) Amplitude spectrum of one of the images in the study in log-

442 log coordinates. The horizontal plane corresponds to the two-dimensional Fourier

443 frequency domain and the vertical dimension to the (log) of the amplitude spectrum.

444 (b) Set of circular regular $1/f$ cones (hence, with a slope of -1 in log-log coordinates)

445 with different values for the gain. (c) Best fit amongst the set of circular regular

446 cones in (b) to the amplitude spectrum shown in (a). (d) Residuals with respect to

447 the best fit shown in (c).

448

449 Figure 4. (a) Scatter plot of the average amplitude of the oxyhaemoglobin response

450 against the average residual score in Experiment 3. (b) Scatter plot of the average

451 amplitude of the oxyhaemoglobin response against the average discomfort rating in

452 Experiment 3. The black lines are illustrative and correspond to a linear least mean

453 square fit.

454

455 Figure 5. Oxyhaemoglobin response to images of buildings with high and low residual

456 scores. Eight of the 10 images with high residual scores were judged uncomfortable

457 to view in Studies 1 and 2. Eight of the 10 images with low residual scores were
458 judged comfortable.

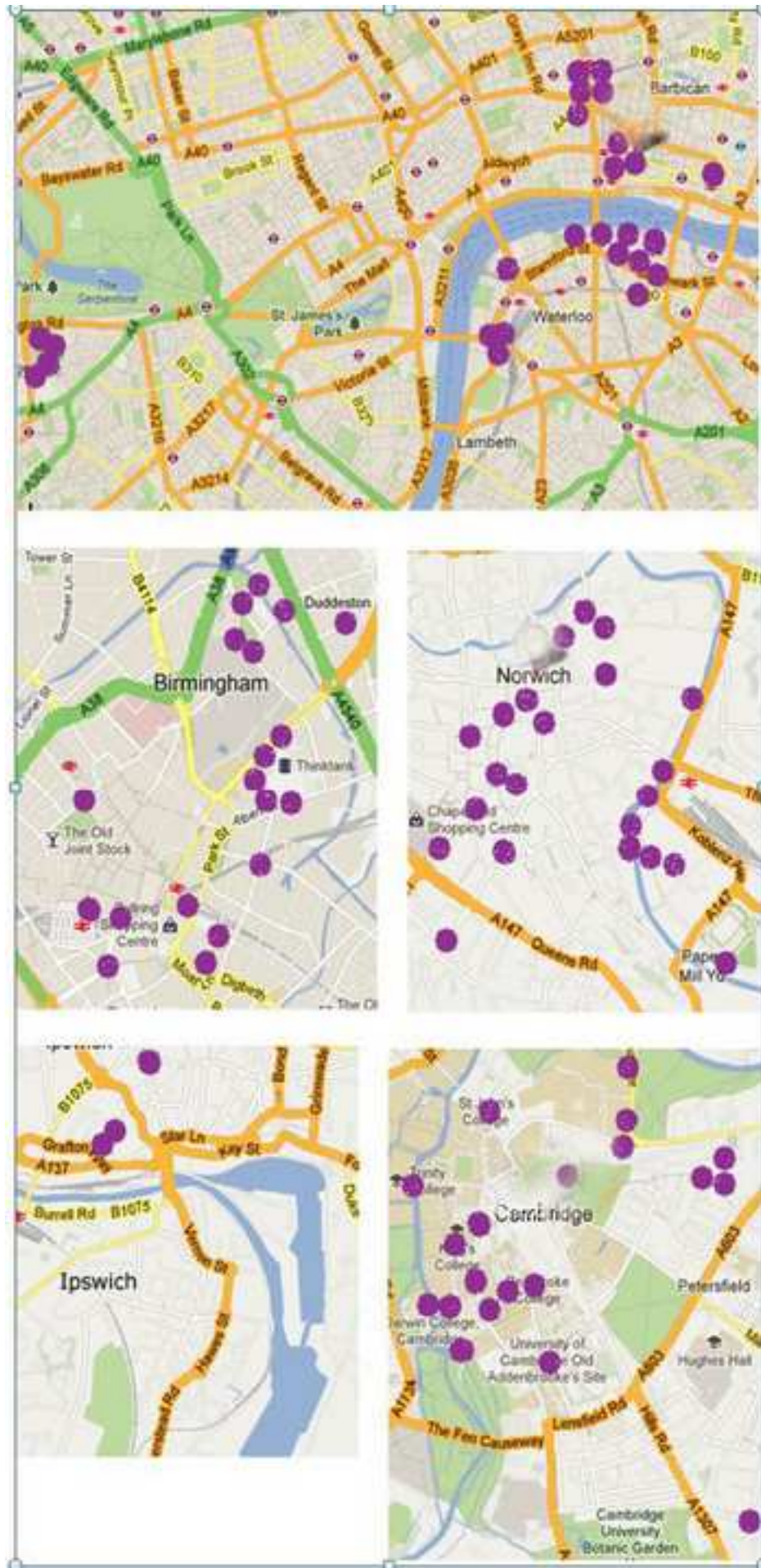
459

460 Figure 6. Examples of views used in Studies 4 and 5.

461

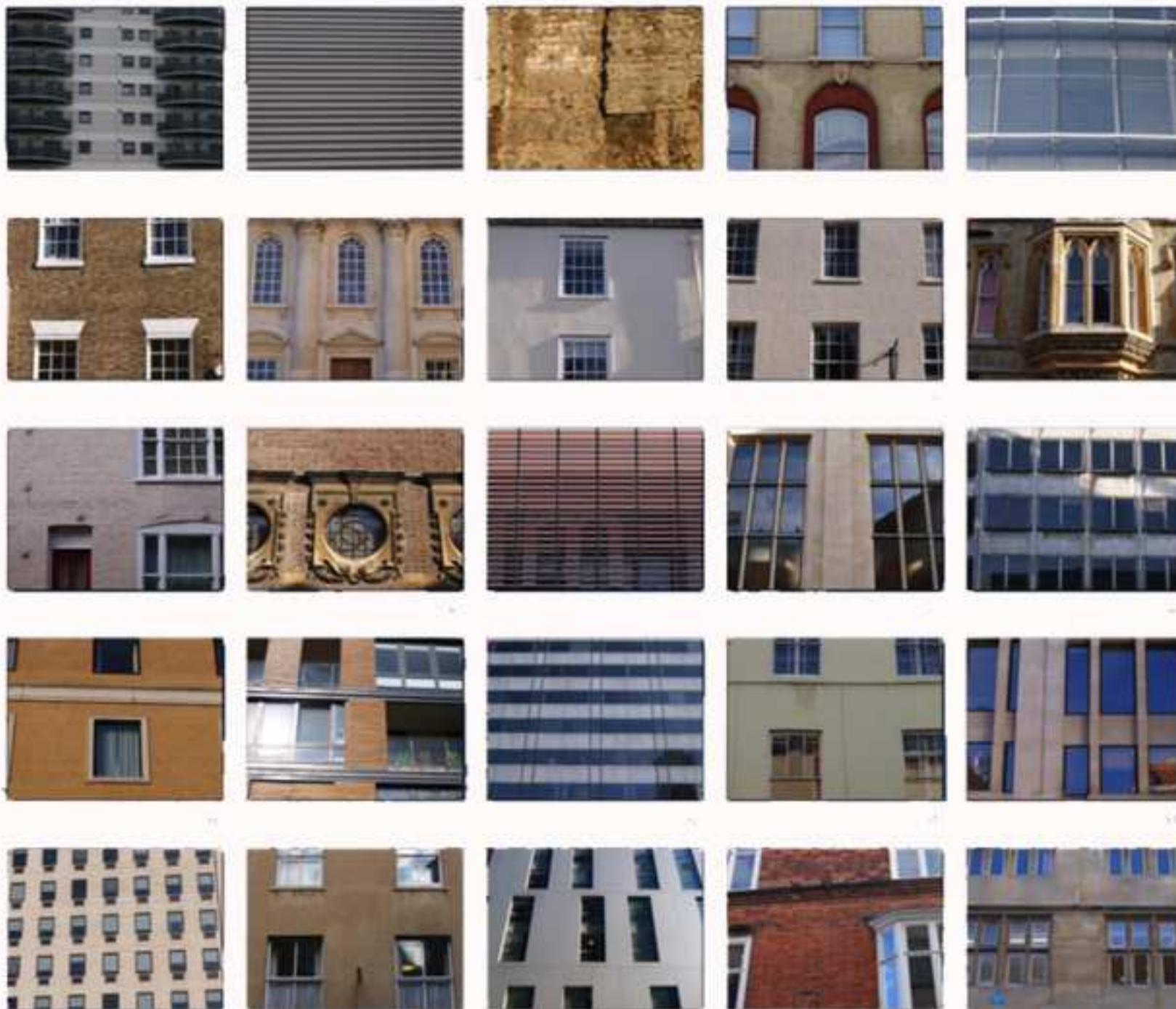
Figure

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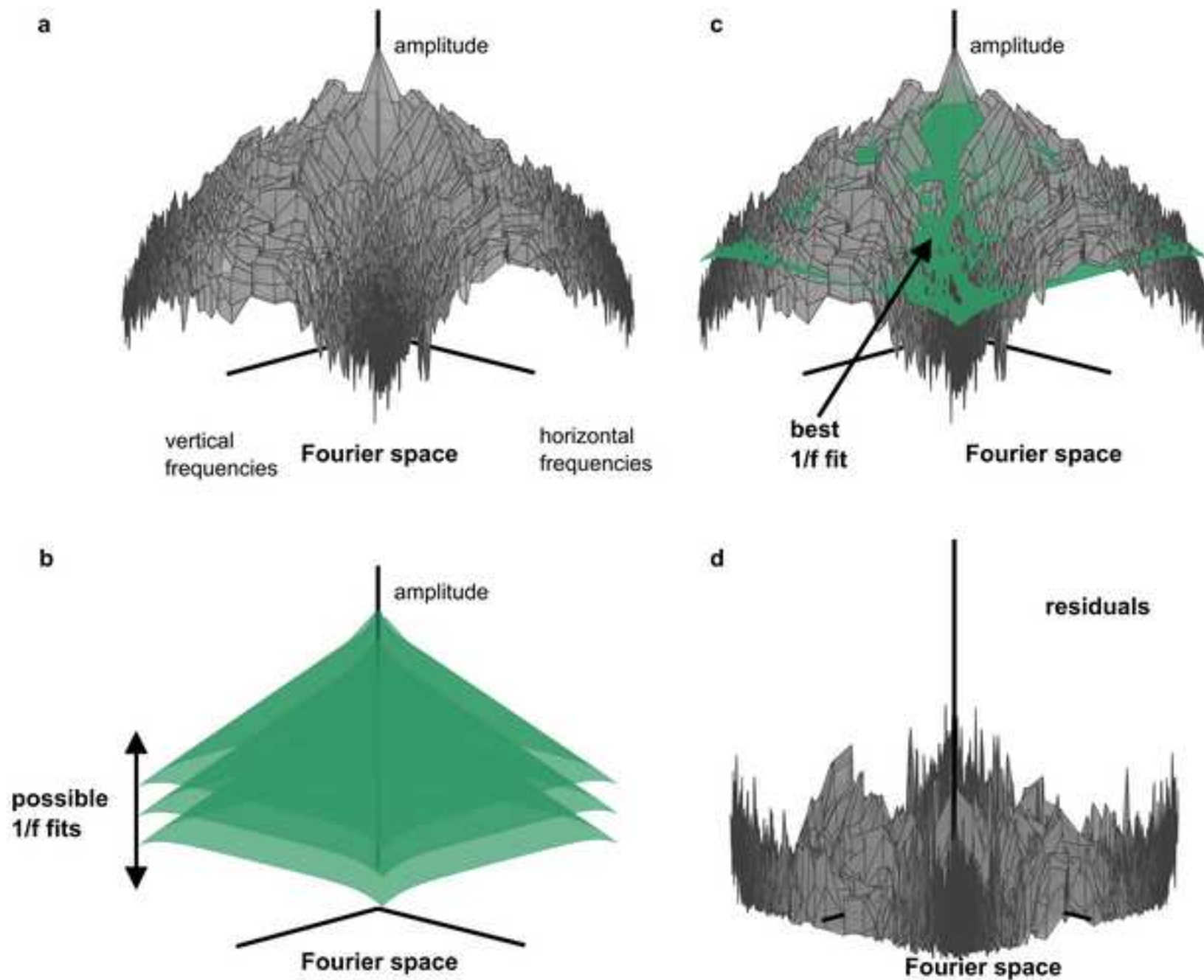


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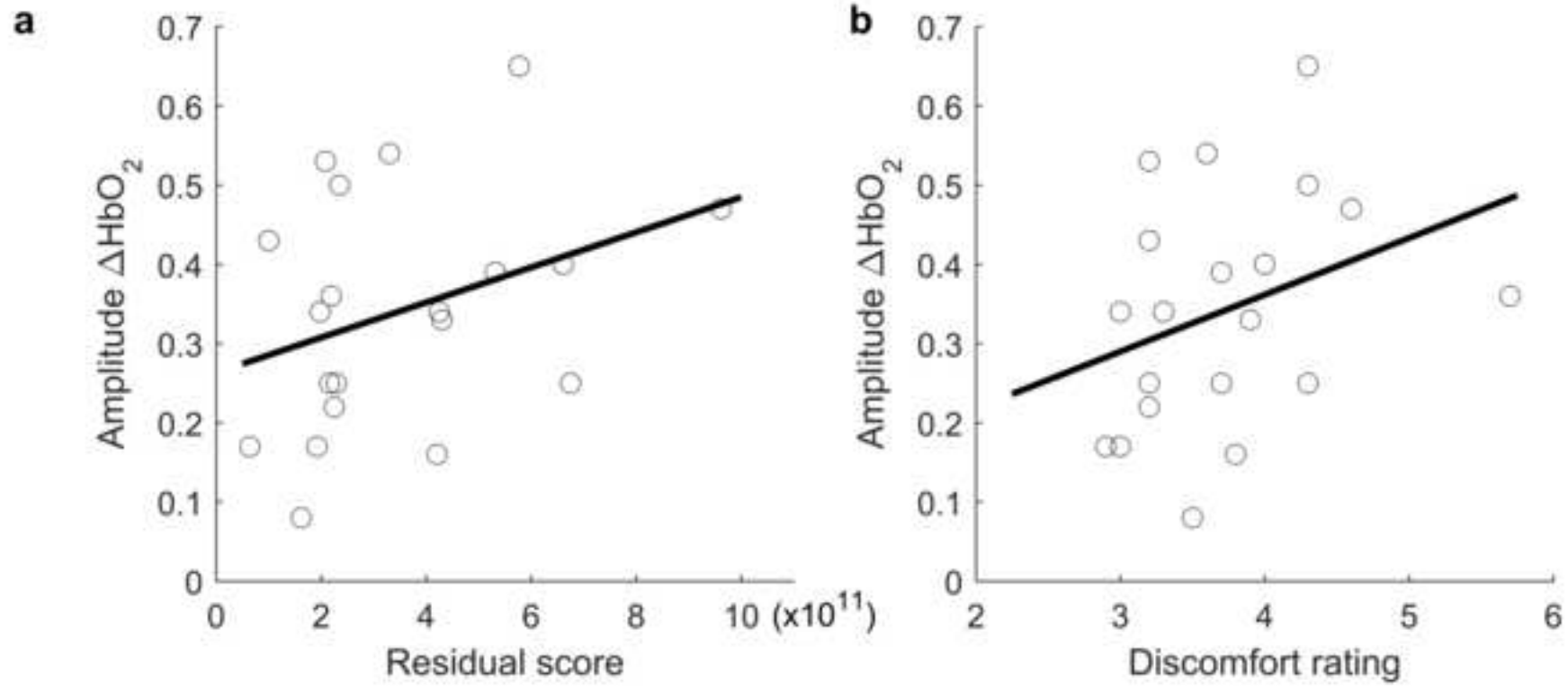
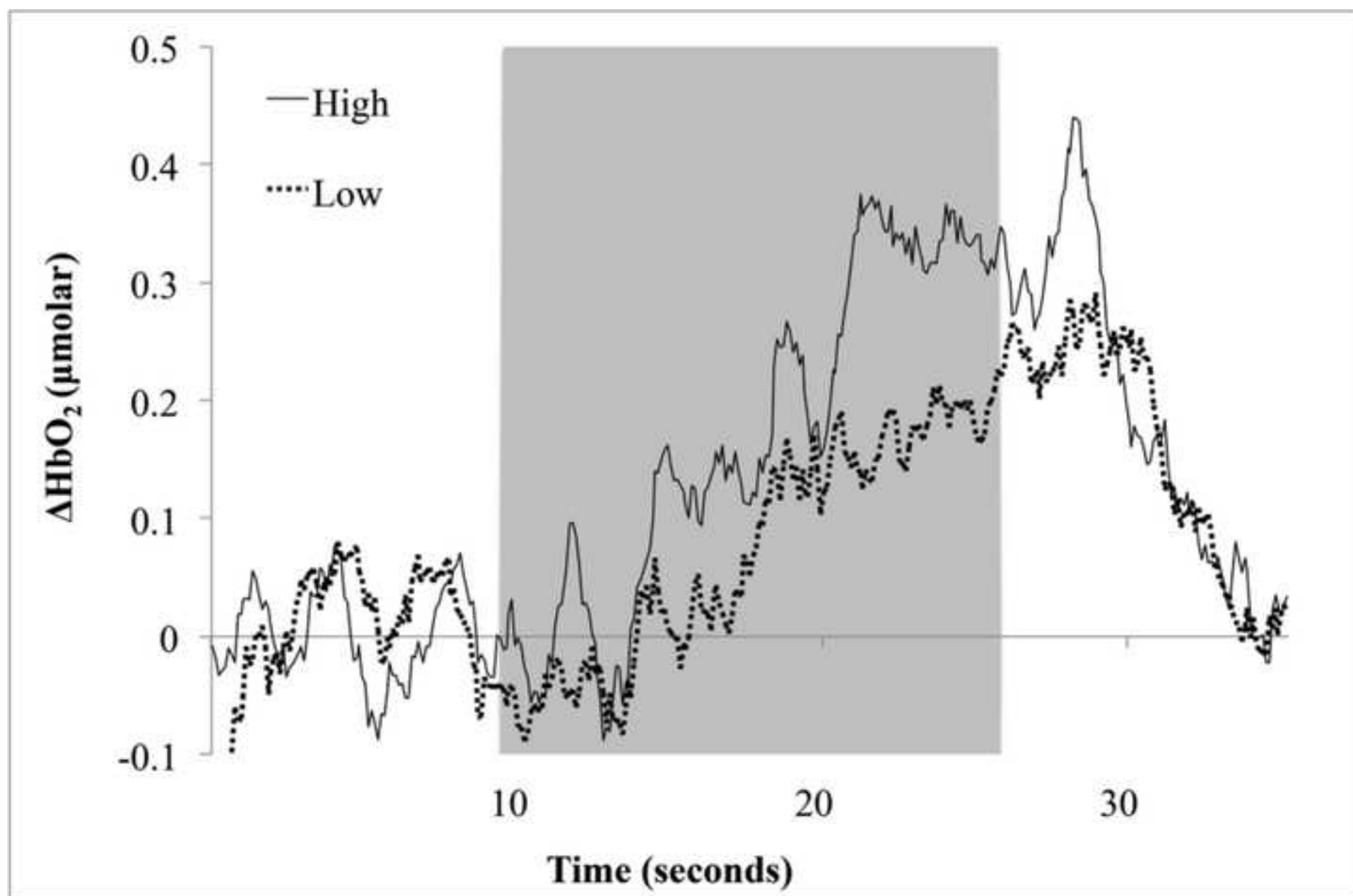


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Acknowledgments

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