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2   Running Head: SEARCH ADVANTAGE FOR HAPPY FACES

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6   Sweet Emotion: The Role of Odor-induced Context in the Search Advantage for Happy Facial

7   Expressions

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26

27   Abstract

28   The current study investigated the extent to which the concurrent presentation of pleasant and

29   unpleasant odors could modulate the perceptual saliency of happy facial expressions in an

30   emotional visual search task. Whilst a search advantage for happy faces was found in the no

31   odor and unpleasant odor conditions, it was abolished under the pleasant odor condition.

32   Furthermore, phasic properties of visual search performance revealed the malleable nature of

33   this happiness advantage. Specifically, attention towards happy faces was optimized at the

34   start of the visual search task for participants presented with pleasant odors, but diminished

35   towards the end. This pattern was reversed for participants in the unpleasant odor condition.

36   These patterns occur through the emotion-inducing capacities of odors and highlight the

37   circumstances in which top-down factors can override perceptually salient facial features in

38   emotional visual search.

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40   Keywords: olfactory perception; emotions; happiness; facial features; visual search

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42   Sweet Emotion: The Role of Odor-induced Context in the Search Advantage for

43   Happy Facial Expressions

44 **Introduction**

45   Odors have been shown to centrally interact with a range of biological and cognitive

46 processes (Bensafi et al. 2002; Li et al. 2007; Moss et al. 2008; Moss et al. 2010),

47 including their potent ability in unlocking our seemingly forgotten memories (Chu and

48 Downes 2000). Their subjective ratings of pleasantness and unpleasantness affect not only

49 how we feel (Black 2001), but also the quality of our emotional attachments with other

50 humans (Sookian et al. 2011). Their ability to evoke approach and avoidance affective

51 reactions helps to mobilize an organism for "fight or flight" action through the neural

52 interconnections between the olfactory receptors and the brain's emotion processing hub,

53 the amygdala, which is located only one synapse away (Boesveldt et al. 2010). In humans,

54 further pathways from the amygdala feed into an intricate network implicated for the

55 visual analysis of faces in the occipitotemporal cortex (inferior occipital gyrus and

56 superior temporal sulcus; Adolphs 2002; Damjanovic et al. 2017), thus allowing for the

57 rapid, emotional appraisal of the most socially important visual cue in our environment –

58 the human face.

59   Whilst the insula, amygdala, primary sensory and orbitofrontal cortical regions in the

60 human brain are involved in the perception of aversive stimuli in all five sensory

61 modalities, a particularly elusive issue is whether olfaction and face perception influence

62 each other in emotion specific ways (Phillips and Heining 2002). Leppänen and Hietanen

63 (2003) provide one of the first attempts to systematically test the level of specificity in

64 olfactory-visual processing of affective information. In their study, healthy participants

65 were required to complete a forced-choice decision task categorizing facial expressions of

66   happiness and disgust taken from the Ekman and Friesen (1976) database. Each facial

67   expression was individually presented at central fixation on the computer screen and

68   participants were required to identify, by button press, as quickly as possible the

69   emotional expression portrayed. In a between-subjects design, some of the participants

70   performed the task whilst they were exposed to a pleasant odor whilst another group of

71   participants performed the task whilst they were exposed to an unpleasant odor. A third

72   group of participants also performed the task under neutral (i.e., no odor) conditions.

73   Whilst there was an overall advantage for categorizing happy facial expressions, this

74   varied as a function of the odor context, such that the categorization of happy faces was

75   facilitated in the context of pleasant odor relative to the no odor control condition, but

76   impaired when presented with an unpleasant odor. The different odor contexts did not

77   affect the processing of facial expressions of disgust. These findings suggest that whilst

78   some facial expressions may be easier to recognize on the basis of unique low-level

79   features, such as the brightness of a smile in happy facial expressions, their perception is

80   nonetheless affected by the context in which it is encountered. In the case of Leppänen

81   and Hietanen's (2003) findings, the authors propose that the improved recognition of

82   happy faces in the pleasant odor context is achieved by increasing the accessibility of

83   positive emotions, which in turn enhances the perceptual processing of emotion-congruent

84   aspects of the facial signal.

85   Building on this important work, Leleu et al. (2015) discovered that some emotional

86   expressions are affected more strongly by different odor contexts than others. For

87   instance, facial expressions of anger and disgust were perceived correctly at lower

88   stimulus intensities when presented in an aversive odor context (i.e., butyric acid) than in

89   both the pleasant (i.e., strawberry) and no odor contexts. The perception of happiness was

90   achieved at lower stimulus intensities when presented in the pleasant odor context than in

91   the control and aversive contexts. However, participants were not significantly influenced

92   by the different odor contexts in their perceptual judgments of fear and sadness. Whilst

93   the facilitative effects found for happy facial expressions paired with the pleasant odor are

94   consistent with the view that odor contexts can improve access to conceptual and/or

95   emotional structures of affective stimuli at ambiguous low-stimulus intensities, such

96   access may not always operate in a category-specific way. Thus, in some instances

97   aversive odor contexts can facilitate the perception of some negative emotional

98   expressions such as anger and disgust, but not others, such as sadness and fear.

99   However, investigations focusing on the neural basis of this response facilitation by

100   odorant primes have produced somewhat equivocal results. For example, Seubert et al.

101   (2010a; 2010b) utilized a repeated measures design for the administration of pleasant,

102   unpleasant and neutral odors whilst participants categorized happy, disgusted and neutral

103   facial expressions. In contrast to Leppänen and Hietanen's findings, the study by Seubert

104   and colleagues found facilitated response times for facial expressions of disgust

105   irrespective of the emotional valence of the odorant prime. For happy faces the effects of

106   the different odorant primes was less consistent: resulting in non-significant effects on

107   reaction times in some instances (2010a), yet in others reaction times to happy faces were

108   considerably impaired for both pleasant and unpleasant relative to the neutral odorant

109   (2010b). This behavioural facilitation for facial expressions of disgust corresponded to

110   neural modulations in the fusiform gyrus, middle frontal and middle cingulated gyrus,

111   with category specific modulations found for disgust faces-unpleasant odor pairings in the

112   anterior insula. Thus, whether the odorant is pleasant or unpleasant, its effect on vision

113   appears to be highly specialized; facilitating the perception of social cues that literally

114   convey "bad taste" (i.e., disgust).

115

116   Determining whether odor contexts can modulate emotion perception in a category-

117   specific manner is likely to be influenced by a range of factors, ranging from the

118   experimental design and the dependent variables of interest within a given study (e.g.,

119   accuracy, response times, self-report ratings, etc.,) to the ontological properties of the

120   odorants themselves. For instance, Zhou and Chen (2009) created their odor contexts from

121   sweat samples collected from participants whilst they watched video segments selected to

122   induce fear and found that participants were more likely to judge an ambiguous facial

123   expression as displaying fear when they were exposed to the chemosignal of fearful sweat,

124   as compared to the control pad. Thus, the perception of low intensity fearful expressions

125   appears to be susceptible to odor facilitation when the context is created from fear-related

126   chemosensory stimuli with socio-communicative functions (i.e., body odors) rather than

127   common odors. This may partly be due to differential processing between common odors

128   and body odors, with research by Lundström et al. (2008) showing how body odors

129   activate brain networks consisting of the posterior cingulate cortex, occipital gyrus,

130   angular gyrus and the anterior cingulate cortex – a network typically implicated in

131   processing of emotional stimuli and the regulation of attentional resources (e.g., Botvinick

132   et al. 1999; Maddock, 1999), whilst deactivating other regions that have previously been

133   linked to olfactory perception of common odors (e.g., piriform cortex and orbitofrontal

134   cortex).

135   Whilst a number of methodological issues could account for the discrepancy in results

136   between the work of Leppänen and Hietanen (2003) and Seubert and colleagues (2010a;

137   2010b), a key issue that both studies agree on is the need to test the effects of odorant

138   primes under complex face processing tasks. Asking participants to categorize a single

139   facial expression presented at a fixed central location is not likely to exert a particularly

140   demanding constraint on attentional resources, especially when response categories are

141   explicitly primed (see also Leleu et al. 2015). Indeed, such experimental tasks result in

142   ceiling levels of performance which are likely to mask any contextual effects provided by

143   the odorant primes. To further clarify the role of odorant primes on face processing, it is

144   important to investigate how they affect the spatial distribution of attentional resources.

145   This is an important issue to address given that a considerable amount of our everyday

146   attentional processing for facial expressions occurs in the context of surrounding facial

147   expressions.

148   The obvious ecological appeal to studying how we detect positive and negative facial

149   expressions in a crowd of faces has been measured with the face in the crowd effect

150   paradigm (FICE). Modelled on classic principles of visual search (e.g., Treisman and

151   Gelade 1980), the FICE paradigm involves the presentation of a target face against an

152   array of competing distracter faces on the computer screen. On some trials all the faces in

153   the display show the same emotional expression, whereas in others, one face differs in

154   emotion from the remaining faces in the crowd. Participants are instructed to discriminate

155   between the "same" or "different" trials via a response key. The main independent

156   variable of interest is the manipulation of the target face on these "different" display trials.

157   Using response time and accuracy to detect the discrepant face in the display, some of the

158   earliest FICE findings showed that participants were faster and more accurate in shifting

159   their attentional resources towards the target face when it portrayed an angry facial

160   expression than a happy one (e.g., Hansen and Hansen 1988; Öhman et al. 2001).

161   Referred to in the FICE literature as the anger or the threat superiority effect (e.g., Fox

162   and Damjanovic 2006; Pinkham et al. 2010), this detection advantage is often attributed to

163   an evolutionarily-driven neural mechanism that enables rapid deployment of attentional

164   resources to stimuli that signal immediate danger and attack in the observer's visual

165   environment (Öhman et al. 2001; Öhman and Mineka 2001) which can be heightened

166 even further through threat-relevant training (e.g., Damjanovic et al. 2014). Thus, when

167 attentional resources are relatively fixed, as in the categorization tasks used by Leppänen

168 and Hietanen, happy faces show a processing advantage over negative expressions such as

169 disgust. However, under greater attentional competition, as measured by the FICE, angry

170 faces not happy ones yield the processing advantage.

171 The predominance of threat superiority findings using FICE has however waned in

172 recent years. This has been mainly due to an increasing number of studies documenting

173 how happy faces, not angry ones, are detected faster and with greater accuracy, yielding

174 what is referred to in the literature as the happiness advantage or the happiness superiority

175 effect (e.g., Calvo and Nummenmaa 2008; Damjanovic et al. 2010; Damjanovic and

176 Santiago 2016; Juth et al. 2005; Lipp et al. 2009). Although more and more studies are

177 trying to increase the ecological validity of FICE tasks by using stimuli of photographic

178 facial expressions from established databases rather than schematic drawings, it appears

179 that most of the inconsistencies found in such studies can be accounted for by the

180 presence or absence of low level facial features found across different database types (e.g.,

181 Savage et al. 2013). Recently referred to as the "teeth visibility hypothesis" (Horstmann et

182 al. 2012), this perceptual account states that the presence of exposed teeth is a salient

183 facial feature that drives the advantage of happy faces over angry faces, so much so that

184 systematic manipulations of this facial component can reliably predict which target face

185 is detected most efficiently: when happy facial expressions are conveyed with a "toothy

186 grin" whilst angry faces are conveyed with a closed mouth, happy faces are detected more

187 efficiently. Conversely, when angry facial expressions are conveyed with a "toothy snarl"

188 whilst happy faces are conveyed with a closed smile, angry faces are detected more

189 efficiently. However, further studies on this specific issue have questioned the extent to

190   which a perceptual account can exclusively accommodate the detection advantage for

191   happy facial expressions.

192   Using computer generated facial expressions of anger and happiness and embedding

193   them within the FICE, Becker and colleagues (2011) reported more efficient detection

194   times for happy face targets even when the amount of perceptual information was

195   identical between angry and happy faces. Providing the following evolutionary and

196   affective accounts, Becker et al argue that happy facial expressions have evolved to be

197   highly visually salient in our environment, as a means of alerting us to important social

198   affiliation cues required to facilitate group membership and integration. Happy facial

199   expressions therefore have become serviceable for the specific purpose of signalling

200   friendship under a range of circumstances including their detection across long distances

201   (e.g., Hager and Ekman 1979) and in instances when the emotion is less intensely

202   expressed (Becker et al. 2011; Becker et al. 2012). As such, happy faces are encountered

203   in our lifetime with greater frequency in our social environment relative to negative

204   emotions (e.g., Bond and Siddle 1996; Whalen, 1998), and in turn biases our expectancy

205   for positive outcomes over negative ones (e.g., Chipchase and Chapman 2007; Diener and

206   Diener 1996). A direct consequence of such frequency effects is that positively laden

207   affective information becomes preferentially processed over negative information.

208   However, when the competing negative affect is overly arousing, any attentional bias

209   towards happy faces may diminish, opening up the prioritization of threat-specific cues,

210   such as angry faces, instead.

211   To summarize, categorization tasks focus on emotion perception under fixed

212   attentional demands whereas FICE tasks are mainly concerned with how attention is

213   distributed across several facial expressions. However, both methodologies have attracted

214   considerable theoretical debate in terms of whether the processing of facial expressions of

215   emotion can be more appropriately accounted for by perceptual-based explanations or

216   affective ones. The current study makes a new contribution to this area by using the

217   contextual cues created by odors which have been extensively applied in categorization

218   tasks, but never included in tasks measuring spatial attention performance with emotional

219   faces. The main aim of the study is to investigate for the first time the effects of different

220   odorant primes on the happiness superiority effect using the FICE task.

221   **The present study**

222   As noted in the above review, the happiness superiority effect can to a large extent be

223   determined by the type of stimuli used in FICE display trials (e.g., Becker et al. 2011;

224   Becker et al. 2012; Juth et al. 2005). The FICE task used in the current study was selected

225   to satisfy two important aims: to elicit a consistent happiness superiority effect within the

226   participant sample recruited for the study and to be sufficiently complex in task demands

227   to allow for the different odorant primes to take effect (e.g., Leppänen and Hietanen 2003;

228   Seubert et al. 2010a; 2010b). The FICE task developed in some of our earlier work

229   satisfies these criteria, demonstrating a robust happiness superiority effect by native

230   English-speaking Caucasian participants across three experiments, although for some

231   variants of the FICE task, the detection of happy face targets was easier than others.

232   The current study used the 'crowd' variant of Damjanovic et al's FICE task, using

233   angry, happy and neutral face stimuli taken from the Caucasian set of the Matsumoto and

234   Ekman's Japanese and Caucasian Facial Expressions of Emotion (JACFEE) database.

235   Developed in 1988, the database was validated by using the Facial Action Coding System

236   (FACS), a technique that enables the objective measurement of facial muscle innervations

237   specific to the emotion portrayed (Ekman et al. 2002). This allowed the facial expressions

238   to be carefully matched for signal clarity and intensity across the different emotional

239   categories (Matsumoto 2002).

240   The happy facial expressions in Matsumoto and Ekman's database were posed with

241   'toothy grins', whilst all of the angry face exemplars were posed with a downward shut

242   mouth, thus the happiness superiority effect found in Damjanovic et al's study with their

243   Caucasian participants could be accounted for in terms of the teeth visibility hypothesis

244   (Horstmann et al. 2012). The key research question addressed in the current study is

245   whether such a perceptual based explanation of the happiness superiority effect measured

246   by FICE can operate independently of an affectively-valenced environment. Specifically,

247   we hypothesized that if the underlying mechanism of the happiness superiority effect is a

248   perceptual one, the effect should remain stable across the different odor contexts (Becker

249   et al. 2011; Calvo and Marrero 2009; Calvo and Nummenmaa 2008; Damjanovic et al.

250   2010; Juth et al. 2005). This hypothesis was addressed by comparing participants' FICE

251   performance in a no odor (i.e., control) group with participants who performed the task

252   under different affectively-valenced environments created by the concurrent presentation

253   of pleasant or unpleasant odorant primes. The experiment used a between-subjects design

254   and long-term odorant exposure in order to assess whether exposure to the odorants

255   influenced the emotional state of the participant during the FICE task.

256   Whilst obtaining faster detection times for happy face targets in the pleasant odor

257   condition would be consistent with the findings obtained in Leppänen and Hietanen's

258   work (2003), the exact mechanism for such odor effects remains elusive. On the one hand,

259   Leppänen and Hietanen suggest that pleasant odorants may operate in a mood-congruent

260   manner, by activating positive emotions within the participants, which in turn facilitates

261   access to conceptual knowledge about the target emotion (e.g., smiling faces), yet whether

262   this cognitive facilitation is achieved independently of any emotional change within the

263   participant remains unknown. Indeed, the majority of studies that have examined the

264   emotion inducing properties of different odorants have found significant changes within

265   the participant across a variety of measures (Krippl 2003). For example, at a

266   physiological level, the affective properties of odors have been shown to exert a direct

267   influence on a participant's level of autonomic nervous system activity, such that an

268   increase in an odor's subjective pleasantness leads to a decrease in the participant's heart

269   rate (Bensafi et al. 2002). Furthermore, exposure to different types of odorants such as

270   ylang-ylang, have successfully been found to increase self-reported levels of calmness and

271   reduce anxiety (Moss et al. 2008; Moss et al. 2010; Moss and Oliver 2012). Based on

272   these observations, it is highly plausible for the facilitative effects observed in Leppänen

273   and Hietanen's study to have occurred as a consequence of a change in the emotional state

274   of the participant. Therefore, it would be important to establish whether the effects of

275   odors on cognitive performance in the FICE task can occur independently of the

276   emotional state of the observer. This will be achieved in the current study by

277   administering a measure of self-reported anxiety, the State-Trait Anxiety Inventory

278   (STAI; Spielberger et al. 1983) in a pre vs post-test measure design. This type of measure

279   has been applied effectively in previous research with FICE tasks (e.g., Damjanovic et al.

280   2014) and utilized in the perception of chemosensory stimuli (Zhou and Chen 2009) to

281   assess self-reported anxiety in participants. As such, utilizing the STAI in a pre vs post

282   test design will allow us to assess if the odorants in the current study influence anxiety and

283   if so, what are the implications of such modulations on attentional performance.

284   Specifically, we hypothesized that pleasant odorants would reduce self-reported measures

285   of anxiety, whilst unpleasant odorants would increase self-reported measures of anxiety.

286   Furthermore, if these hypotheses are confirmed in our analyses, we will examine the

287   extent to which such changes in self-reported anxiety mediates the attentional

288   performance in detecting happy facial expressions.

289   Finally, given that differences in experimental design and odor exposure intervals are

290   both likely to influence mood-inducing capacities of odors and other associated affective

291   states (see Seubert et al. 2010b), a further consideration for the present study is to

292   determine whether odors exert a specific time course on emotion perception. This is

293   because the olfactory modality is particularly vulnerable to habituation; with repeated or

294   prolonged exposure to an odorant stimulus, neural sensitivity is reduced, consequently

295   reducing its saliency and priming potential (Dalton 2000). For instance, Moessnang,

296   Finkelmeyer, Vossen, Schneider and Habel, (2011) showed that participants' spatial

297   attention to locate a target shape presented on the same side as an odorant cue was initially

298   slower at the start of the experiment, but then disappeared over the course of the

299   experiment. Performing a similar time course split on reaction time will help to establish

300   to what extent the search for happy faces remains stable over the course of the experiment.

301   **Method**

302

303   **Participants**

304   A total of 54 Undergraduate and Postgraduate students from the University of Chester

305   were randomly allocated in equal groups to the control (female = 13, male = 5; mean age:

306   23.72 years, range: 19-39 years), pleasant odor (female = 15, male = 3; mean age: 21.94

307   years, range: 18-40 years) and the unpleasant odor condition (female = 15, male = 3; 23.11

308   years, range: 18-48 years).

309   **Ethics Statement**

310   The work with human participants complies with the Declaration of Helsinki for

311   Medical Research involving Human Subjects. The study was also approved by the

312   Department of Psychology Ethics Committee at the University of Chester, United Kingdom.

313   All participants gave written informed consent and were paid £5.00 for participation.

314   Participants self-reported that they had normal to normal-to-corrected vision, normal sense of

315   smell, and no nasal or food allergies and were not experiencing any respiratory problems.

316   Female participants who were pregnant or thought that they might be pregnant were excluded

317   from participating in the study to minimize the risk of nausea. Once each participant's testing

318   date and time was confirmed, they were reminded to restrict some habits that could affect

319   their ability to smell, such as smoking, drinking coffee and using scented products, on the day

320   of testing. They were also reminded of these restrictions 24 hours before their day of testing.

321

322   **Stimuli and apparatus**

323   Based on previous research by Leppänen and Hietanen (2003) that utilized an

324   unbalanced design towards positive odors, we selected strawberry (contains: ALDEHYDE

325   C16 (STRAWBERRY PURE), METHYL CINNAMATE, alpha iso methyl ionone, amyl

326   cinnamic aldehyde), vanilla (contains: VANILLIN, limonene, coumarin, ETHYL MALTOL,

327   Tonalid) and orange zest odors (contains: Linalyl Acetate, citral, limonene, linalool) for the

328   pleasant odor condition, and for the unpleasant condition we selected a fish odor (contains:

329   PINE TAR OIL, Alpha-Cedrene) (Boesveldt et al. 2010). All odorants were manufactured

330   and supplied by *Dale Air™* in the U.K. For the main experiment, the odors were supplied in

331   aerosol form and distributed by a purpose-built dispenser supplied by *Dale Air™* positioned 2

332   metres above floor level. The odor release mechanism was set to 20 minute intervals. Cotton

333   wads absorbed with the liquid form of the odors and presented in containers were used to

334   collect ratings of arousal and pleasantness in a separate rating study and as part of the odor

335   selection stage of the main experiment.

336

337   **Odor rating study**

338   A separate group of 36 student participants from the same population and matched for

339   male-female split as those recruited from the main experiment were randomly allocated in

340   equal groups to the pleasant (female = 15, male = 3; mean age: 30 years, range: 18-53 years)

341   and unpleasant odor conditions (female = 15, male = 3; 22 years, range: 18-42 years). Each

342   participant in the pleasant odor group was presented with three individual containers

343   containing the odors and asked to rate each container on pleasantness and arousal using a 5-

344   point scale. Thus, all participants in the pleasant odor group smelled all of the pleasant odors.

345   As per Leppänen and Hietanen's (2003) pleasantness ratings, participants were instructed to

346   sniff each container and evaluate it on a 5-point Likert scale ranging from 1 (*extremely*

347   *unpleasant*) to 3 (*neutral*) to 5 (*extremely pleasant*). Measures of arousal were obtained by

348   adapting the instructions and response categories used by Bensafi et al. (2002, p. 705),

349   whereby participants were instructed to 'Please judge your feeling when you smelled the

350   odorant by circling the relevant number between 1 (*not at all arousing*) to 3 (*neutral)* to 5

351   (*extremely arousing*)'. The mean value provided for each odorant for both pleasantness and

352   arousal measures were used to obtain a further measure of perceived intensity by conducting a

353   series of one-sample *t*-tests with the mid-point value as the hypothetical neutral value.

354

355   **Measures of pleasantness:** A one-way independent groups ANOVA revealed a significant

356   difference for pleasantness ratings for strawberry ($M = 4.28$, $SD = .96$), vanilla ($M = 4.28$, SD

357    $= .75$), orange zest ($M = 3.94$, $SD = .73$), and the fish odor ($M = 2.17$, $SD = 1.10$), $F (3, 68) =$

358   22.94, $MSE = .80$, $p < .001$, $\eta p^2 = .50$. Planned comparison t-tests showed that whilst there

359   were no significant differences in pleasantness ratings between strawberry, vanilla and orange

360   ($p > .05$), each pleasant odor however was associated with significantly higher ratings than

361   the fish odor; strawberry, $t (34) = 6.15$, $p < .001$, $d = 2.05$, vanilla, $t (34) = 6.73$, $p < .001$, $d =$

362   2.27, orange zest t (34) = 5.73, p < .001, d = 1.92. Furthermore, one sample t-tests confirmed

363   that both pleasant and unpleasant fish odor ratings differed significantly from the neutral mid-

364   point (p < .001), with pleasant odors being rated significantly more towards the pleasant end

365   of the scale and the fish odor being rated significantly more towards the unpleasant end of the

366   scale.

367

368   **Measures of arousal:** Strawberry (M = 3.44, SD = 1.20), vanilla (M = 3.11, SD = 1.28),

369   orange zest (M = 2.94, SD = 1.47), and the fish odor (M = 2.89, SD = 1.32), did not differ

370   significantly from each other in terms of perceived arousal, F (3, 68) = .64, MSE = 1.75, p =

371   .590, ηp^2 = .03 or from the neutral mid-point. Thus, the odors selected for the main

372   experiment differed significantly in terms of their affective valence (pleasant vs unpleasant),

373   but were not confounded by differences in stimulus arousal.

374

375   **Main experiment:** Participants in the main experiment were required to rate each odor for

376   perceived pleasantness (1 = extremely unpleasant to 5 = extremely pleasant Likert scale).

377   Each participant in the pleasant odor group was presented with three individual containers

378   containing the pleasant odors, whilst participants in the unpleasant odor condition were given

379   the fish odor to rate. Thus, all participants in the pleasant odor group smelled all of the

380   pleasant odors. A one-way independent groups ANOVA revealed significant differences in

381   pre-experimental ratings for strawberry (M = 4.44, SD = .78), vanilla (M = 4.17, SD = .62),

382   orange zest (M = 4.11, SD = .76), the overall mean for the selected pleasant odor (M = 4.33,

383   SD = .59) and the fish odor (M = 2.0, SD = .59), F (4, 85) = 41.20, MSE = 0.46, p < .001, ηp^2

384   = .66. Mirroring the pattern of results found in the odor rating study, the pleasant odors did

385   not differ significantly from each other (p > .05), but each pleasant odor was associated with

386   significantly higher ratings than the fish odor; strawberry, t (34) = 10.55, p < .001, d = 3.54,

387   vanilla, t (34) = 10.72, p < .001, d = 3.56, orange zest, t (34) = 9.30, p < .001, d = 3.10, and

388   the overall mean for the selected (see procedure) odor, t (34) = 11.78, p < .001, d = 3.95.

389   Furthermore, the pleasant odors and the unpleasant fish odor ratings differed significantly

390   from the neutral mid-point (p < .001).

391   To establish that these differences in pleasantness ratings between the two odor

392   conditions were significant at the end of the experiment as well as at the beginning, further

393   between groups comparisons were conducted, as per Leppänen and Hietanen (2003), by using

394   a 20cm visual analogue scale with the word *unpleasant* at the left end, *neutral* in the middle,

395   and *pleasant* at the right for participants to evaluate the pleasantness of the odor in the room.

396   Responses to the odor evaluations were recorded from 0 to 10 for pleasant responses and from

397   0 to -10 for unpleasant responses. Participants in the pleasant odor condition rated the odor as

398   significantly more pleasant (M = 6.81, SD = 2.12) than participants with the fish odor (M = -

399   5.59, SD = 4.53), t(34) = 10.52, p < .001, d = 3.72. Both ratings differed significantly from

400   the mid-point (i.e., neutral) as revealed by one sample t-tests for fish, t(17) = -5.23, p < .001, d

401   = 1.23 and the selection of odors, t(17) = 13.64, p < .001, d = 3.21 respectively. Thus, the

402   unpleasant and pleasant evaluations associated with fish and the pleasant odors at the start of

403   the experiment were maintained towards the end of the experiment.

404

405   **Facial expression stimuli:** Four angry (E1-E4), four happy (E33-E36) and 8 neutral (N6, N8,

406   N11, N13, N17, N22, N26, N27) faces were selected from the Caucasian set of Matsumoto

407   and Ekman's (1988) database. Adobe Photoshop converted each color image to grayscale and

408   applied an oval template (125 pixels wide by 168 pixels high) to remove external features

409   (e.g., hair, ears, neckline). Mean luminance and contrast were matched for all faces such that

410   each face generated an intensity value of 190. Stimulus presentation and data recording was

411   obtained through SuperLab 4.0, using a Mac G4 OSX computer.

412

Design

414   The happiness superiority effect was measured using reaction time (RTs) recorded

415 from the onset of each visual search display to participant response and error rates on

416 'different' display trials (Damjanovic et al., 2010). Participants were randomly allocated to

417 one of the three groups: control, pleasant or unpleasant. Type of target (angry and happy) and

418 type of distracter (neutral and emotional) were administered as repeated measures variables.

419 The anxiety inducing properties of the odors was established by comparing state anxiety

420 scores pre and post odor exposure. Participants in the control condition were also required to

421 provide self-report measures of their state anxiety, once before completing the visual search

422 task and immediately after its completion.

423

Procedure

425   The procedure involved several measures administered in the following order: rating

426 of the odor(s), state anxiety, visual search task, rating of the odor and state anxiety. The odor

427 rating measures were not applicable to participants in the control (i.e., no odor condition). For

428 participants in the pleasant odor condition, the odor that they rated the highest for

429 pleasantness was selected for the visual search task, whereas for participants in the unpleasant

430 odor condition it was the fish odor. Thus, participants in the odor conditions were exposed to

431 one odorant for the visual search task. Participants then completed the state (S) component of

432 the STAI (Spielberger et al. 1983) as an index of their baseline anxiety. The visual search task

433 was taken from Experiment 1 in Damjanovic et al.'s study (2010). Briefly, this consisted of

434 *same* display trials of four different individuals displaying the same emotional expression

435 (i.e., all angry, all happy or all neutral). There were four *different* display trials: one angry,

436 three neutral; one angry, three happy, one happy, three neutral; and one happy, three angry.

437   The visual search experiment consisted of 96 same-display trials (32 angry, 32 happy, 32

438   neutral expressions) presented randomly with 128 different-display trials (32 in each of the

439   four conditions). A fully counterbalanced design in which each poser provides each

440   expression was not possible to implement in the current study due to the fact that each poser

441   only contributed one facial expression of emotion and one neutral expression to the database

442   (Matsumoto 2002; Matsumoto and Ekman 1988).

443   Each trial began with a fixation cross in the centre of the screen for 500 ms followed

444   by a display of four faces surrounding the central fixation point for 800 ms. The four faces

445   were arranged in an imaginary circle, occupying top, right, bottom and left locations on the

446   computer screen, with a fixation cross at the centre viewed at a distance of 60cm. Each face

447   subtended a visual angle of $3.1°$ horizontally by $4.1°$ vertically. The centre of each face was

448    $6.2°$ of visual angle from fixation. The inter trial interval was set to 2000 ms. Participants were

449   instructed to respond as quickly and as accurately as possible whether the four faces in the

450   display showed the 'same' emotion or whether one was 'different' in emotion from the

451   remaining three faces by pressing the 'x' and '.' key on the keyboard. Response mapping was

452   reversed for half the participants, with feedback in the form of a 1,000 ms beep being

453   provided on incorrect trials. Although participants performed the visual search task without a

454   break, our previous work with these tasks has indicated that this does not necessarily induce

455   severe fatigue effects.

456   After the visual search task, participants in the experimental groups used a 20cm

457   visual analogue scale with the word *unpleasant* at the left end, *neutral* in the middle, and

458   *pleasant* at the right to evaluate the pleasantness of the odor in the room as a post-experiment

459   rating measure. This change in rating method from a 5-point Likert scale to a visual analogue

460   scale follows similar procedural approaches (e.g., Leppänen and Hietanen 2003) and was

461   implemented in the current study to minimize the impact of participants' responses styles on

462   their odor ratings. Finally, participants were provided with the STAI (S) component to

463   complete. Participants were required to complete the STAI (S) after completing the odor

464   rating in order to replicate the administration of the rating scales used in Leppänen and

465   Hietanen's (2003) procedure. To assess whether asking participants to give a positive or

466   negative rating for an environmental factor may subsequently raise awareness of this factor

467   and influence their STAI (S) scores, we correlated participants' pleasantness ratings with their

468   post-experiment STAI(S) score. The relationship between the two measures was weak and

469   non-significant, $r = .07$, $p = .689$, providing little evidence to suggest that rating an odorant's

470   pleasantness is significantly associated with self-reported ratings of state anxiety. Once the

471   STAI was completed, participants were debriefed and thanked for their time.

<div align="center">

Results

</div>

473   **Anxiety-inducing properties of odors:** To test our specific hypotheses that the

474   pleasant odorant would result in a decrease in self-reported anxiety, the unpleasant odorant an

475   increase in self-reported anxiety, and the control condition resulting in a non-significant

476   change, a 3 (group: control, pleasant or unpleasant) x 2 (time: before and after) mixed

477   ANOVA with repeated measures on the last factor was applied to the participants' STAI-S

478   scores (see Table 1). There was no significant effect of group, $F (2, 51) = 0.04$, MSE =

479   132.02, $p = .962$, $\eta p^2 = .00$ or time, $F (1, 51) = 0.02$, MSE = 26.77, $p = .882$, $\eta p^2 = .00$

480   However, the group x time interaction was significant, $F (2, 51) = 7.05$, MSE = 26.77, $p =$

481   .002, $\eta p^2 = 0.22$. There were no significant group differences in state anxiety at baseline, F

482    $(2, 102) = 1.35$, MSE = 79.39, $p = .265$, $\eta p^2 = .03$ or post-test, $F (2, 102) = 1.10$, MSE =

483   79.39, $p = .339$, $\eta p^2 = .02$. However, self-reported anxiety levels changed within each group,

484   such that towards the end of the experiment, anxiety levels significantly decreased in

485   participants exposed to the pleasant odors $F (1, 51) = 8.59$, MSE = 26.77, $p = .005$, $\eta p^2 = .14$,

486   but increased for participants exposed to the unpleasant odor, $F (1, 51) = 4.25$, MSE = 26.77,

487    $p < .044$, $\eta p^2 = .08$. Pre vs post test changes in anxiety did not differ significantly for

488   participants in the control group, $F (1, 51) = 1.27$, $p = .264$, $\eta p^2 = .02$.

489

490   **(Insert Table I about here)**

491

492   **Visual search performance:** As per Damjanovic et al (2010), only performance on

493   discrepant trials were examined. Reaction time (RT) for correct responses on *different display*

494   trials were filtered (< 100ms or $> 2,000$ms) for analysis. To test the hypothesis that the

495   underlying mechanism of the happiness superiority effect is a perceptual one a 3 (group:

496   control, pleasant or unpleasant) x 2 (target: angry and happy) x 2 (distracter: emotional and

497   neutral) mixed ANOVA with repeated measures on the last two factors was conducted.

498

499   **(Insert Figure 1 about here)**

500

501   The main effect of group was not significant , $F (2, 51) = .40$, MSE $= 196657.53$, $p =$

502    $.676$, $\eta p^2 = .02$. The initial results replicated a happiness superiority effect, $F (1, 51) =$

503   30.46, MSE $= 3871.58$, $p < .001$, $\eta p^2 = .37$, and participants were faster to detect a target

504   when it was surrounded by emotional than neutral distracter faces, $F (1, 51) = 73.58$, MSE $=$

505   3974.857, $p < .001$, $\eta p^2 = .59$. Type of target and type of distracter interacted significantly

506   with each other $F (1, 51) = 61.48$, MSE $= 2881.73$, $p < .001$, $\eta p^2 = .55$, with the happiness

507   superiority effect occurring with neutral distracters $F (1, 102) = 86.51$, MSE $= 3376.66$, $p <$

508    $.001$, $\eta p^2 = .46$, but not with emotional distracters, $F (1, 102) = 0.89$, MSE $= 3376.66$, $p =$

509    $.348$, $\eta p^2 = .01$. Angry face targets were found faster overall when they were surrounded by

510   emotional distracters (i.e., happy faces) than when surrounded by neutral distracters, $F (1,$

511    $102) = 134.90$, MSE $= 3428.29$, $p < .001$, $\eta p^2 = .60$, whereas overall response times for happy

512   face targets was equivalent for emotional and neutral distractors, $F(1, 102) = 2.10$, MSE =

513   3428.29, $p = .151$, $\eta p^2 = .02$. The effect of target interacted significantly with group $F(2, 51)$

514    $= 4.58$, MSE = 3871.58, $p = .015$, $\eta p^2 = .15$, producing the happiness superiority effect in the

515   control $F(1, 51) = 24.83$, MSE = 3871.58, $p < .001$, $\eta p^2 = .33$ (See Figure 1A) and

516   unpleasant groups $F(1, 51) = 14.11$, MSE = 3871.58, $p < .001$, $\eta p^2 = .22$ (See Figure 1C),

517   but is eliminated in the pleasant group, $F(1, 51) = 0.67$, MSE = 3871.58, $p = .416$, $\eta p^2 = .01$

518   (See Figure 1B). The three-way interaction between group x target x distracter did not reach

519   significance, $F(2, 51) = 0.45$, MSE = 2881.73, $p = .644$, $\eta p^2 = .02$.

520   Analysis of error rates revealed significantly lower error rates associated with happy

521   targets compared to angry targets, $F(1, 51) = 167.60$, MSE = 118.18, $p < .001$, $\eta p^2 = .77$

522   (See Figure 1) and with emotional distracters compared with neutral ones, $F(1, 51) = 135.33$,

523   MSE = 103.66, $p < .001$, $\eta p^2 = .73$. A significant target x distracter interaction $F(1, 51) =$

524   86.73, MSE = 132.72, $p < .001$, $\eta p^2 = .63$ revealed low error rates for happy targets with

525   both emotional ($F(1, 102) = 245.18$, MSE = 125.45, $p < .001$, $\eta p^2 = .71$) and neutral

526   distracters $F(1, 102) = 4.46$, MSE = 125.45, $p = .037$, $\eta p^2 = 0.04$. For angry targets, detection

527   accuracy was considerably better with emotional distracters $F(1, 102) = 215.56$, MSE =

528   118.19, $p < .001$, $\eta p^2 = .68$, but there was no significant effect of surrounding distracter

529   context on error rates for happy targets, $F(1, 102) = 0.53$, MSE = 118.19, $p = .470$, $\eta p^2 = .01$.

530   The three-way interaction between group x target x distracter did not reach significance, $F(2,$

531    $51) = 0.61$, MSE = 132.72, $p = .549$, $\eta p^2 = .02$.

532   These results show that whilst there is an overall search advantage favouring happy

533   facial expressions, this advantage is modulated by the affectively valenced environmental

534   cues. Furthermore, the presence of the group x target interaction on response times, indicates

535   that such cues exert a stronger effect on processing speed than on accuracy. The emotionality

536   of the competing distracter faces produces similar effects on both search and accuracy

537   measures.

538   **Stability of the search advantage for happy faces:** Habituation effects were

539   investigated by calculating a single computation for each participant for each distracter

540   context, the happiness superiority index (HSI). This calculation involved the mean RTs for all

541   angry targets minus mean RTs for all happy targets, for the first and last 25% of trials for each

542   participant, with a positive value indicating faster detection times for happy faces. A 3 (group:

543   control, pleasant or unpleasant) x 2 (distracter: emotional and neutral) x 2 (phase: first quarter

544   and last quarter) mixed ANOVA with repeated measures on the last two factors (see Figure 2)

545   revealed no significant effects of group $F(2, 51) = 0.15$, MSE = 32876.65, $p = .859$, $\eta p^2 = .01$

546   or phase $F(1, 51) = 0.10$, MSE = 24868.75, $p = .752$, $\eta p^2 = .00$. Greater levels of happiness

547   superiority were observed with neutral relative to emotional distracters $F(1, 51) = 53.26$,

548   MSE = 20381.67, $p < .001$, $\eta p^2 = .51$ (See Figure 2).

549

550   **(Insert Figure 2 about here)**

551

552   The only significant higher order interaction to emerge from the analyses was for

553   group x phase, $F(2, 51) = 6.05$, MSE = 24868.75, $p = .004$, $\eta p^2 = 0.19$, with simple main

554   effects revealing higher levels of happiness superiority in the last quarter of the experiment, F

555     $(2, 102) = 3.62$, MSE = 28872.02 $p = .030$, $\eta p^2 = .07$, an effect which was limited to the

556   unpleasant odor group (Tukey $p < .05$). For participants in the pleasant odor group the

557   magnitude of the happiness superiority effect was stronger at the start of the visual search task

558   than towards the end, $F(1, 51) = 4.44$, MSE = 24868.75, $p = .040$, $\eta p^2 = 0.08$. This pattern

559   was reversed for participants in the unpleasant group, $F(1, 51) = 7.74$, MSE = 24868.75, $p =$

560     $.01$, $\eta p^2 = .13$. The happiness superiority effect did not differ between the start and end of the

561   visual search task for participants in the control group, F (1, 51) = 0.02, MSE = 24868.75, p

562   = .901, ηp^2 = .00.

563

564   **The role of self-reported anxiety in mediating the impact of scent pleasantness on the**

565   **happiness superiority effect.**

566   Given that our hypotheses relating to the anxiety modulating properties of the odorants

567   were supported, the following analyses investigated whether the significant changes in self-

568   reported anxiety reported in the two odor groups (see Table 1) could impact on the happiness

569   superiority index at the start and towards the end of the visual search task (see Figure 2). To

570   achieve this, a change in state anxiety variable was computed (STAI-CHANGE: STAI-S $_{after}$ −

571   STAI-S $_{before}$) with a negative value indicating a decrease in anxiety, and a positive value

572   indicating an increase in anxiety as a function of odor exposure. Focusing on the significant

573   effects found with neutral distracters, odor type (coded: 0 = pleasant, 1 = unpleasant)

574   correlated positively with changes in self-reported anxiety, r_{pb} = .54, $p <$ .001, such that the

575   unpleasant odor was strongly associated with increased levels of self-reported anxiety.

576   Furthermore, the pleasantness of odor type almost yielded a significant relationship with

577   search times for the HSI at the start of the experiment, resulting in a greater HSI with pleasant

578   than unpleasant odors, r_{pb} = -.31, p = .065. The relationship between changes in anxiety and

579   HSI, was negligible, r = -.02, p = .913. In contrast to the patterns observed at the start, as

580   participants approached the end of the visual search task, odor pleasantness was found to

581   significantly correlate with HSI, such that the unpleasant odor was moderately associated with

582   higher levels of happiness detection, r_{pb} = .37, p = .026. The relationship between changes in

583   anxiety and HSI performance was weak and not significant, r_{pb} = .28, p = .104.

584   Given the small sample sizes (Preacher & Hayes, 2008; Shrout & Bolger, 2002), two

585   separate bootstrapped hierarchical regressions for search times at the start and at the end of

586   the visual search task were performed to test the degree to which odor type and changes in

587   state anxiety could predict the magnitude of the HSI. These results are summarized in Table

588   2. At the start of the experiment, type of odor (block 1) accounted for 9.7% of the variation in

589   detecting happy faces, $F(1, 34) = 3.64$, $MSE = 21702.49$, $p = .065$. The inclusion of changes

590   in state anxiety in block 2, accounted for a further 3.1%, but this did not significantly improve

591   the ability of the model to predict happiness detection performance, $F(2, 33) = 2.41$, $MSE =$

592   21594.90, $p = .105$. Inspecting the bootstrapped unstandardized b-values, odor type in block 1

593   approached significance ($p = .058$), but gained full predictive value when included with

594   changes in state anxiety in block 2 ($p = .027$), whilst changes in the state anxiety failed to gain

595   any significant value in predicting happiness detection ($p = .257$). The configuration of these

596   effects is consistent with classical suppression found in regression analyses (e.g., Horst 1941;

597   MacKinnon et al. 2007; McFatter 1979; Paulhus et al. 2004) and demonstrates that knowing

598   how a participant responds emotionally to the odorant during initial stages of exposure

599   significantly improves the detection of emotional facial cues. In the case of the current study,

600   reductions in anxiety created by exposure to pleasant odors facilitate the detection of happy

601   face targets.

602

603   **(Insert Table II about here)**

604

605   In a second hierarchical regression conducted on performance towards the end of the

606   experiment, type of odor (block 1) significantly predicted happiness detection, accounting for

607   13.8% of the variance in performance, $F(1, 34) = 5.44$, $MSE = 24754.00$, $p = .026$, but

608   adding change in anxiety scores (block 2) only increased the variance accounted for by a non-

609   significant 0.8%, $F(2,33) = 2.82$, $MSE = 25267.18$, $p = .074$. Inspecting the bootstrapped

610   unstandardized b-values, odor type in block 1 significantly predicted the detection of

611   happiness, such that the presentation of unpleasant odors improved the magnitude of the HSI

612   (p = .028). However, when changes in state anxiety were controlled for (block 2), neither odor

613   type (p = .14) nor anxiety change (p = .531) were able to significantly predict HSI

614   performance. In this instance, adding changes in anxiety to the model resulted in a

615   redundancy situation (Paulhus et al. 2004), accounting for less than 1% of performance. Thus,

616   towards the end of the experiment, the detection of happy faces is based entirely on the

617   odorant and is independent of any emotional changes that occur within the participant as a

618   result of the odorant prime. In this instance, the role of the odorant prime is reversed, such

619   that participants who were exposed to the unpleasant odor showed improved detection of

620   happy faces relative to participants who were exposed to the pleasant odors.

621

622   **Discussion**

623   In the present study, we investigated the influence of olfactory environmental context

624   on the perception of facial expressions of emotion conveying happiness and anger. Whilst

625   some of the earlier work in this area appears to suggest category-specific facilitative effects of

626   pleasant odorant primes on the processing of happy facial expressions (e.g., Leppänen and

627   Hietanen 2003), very little is known about the generalizability of these findings under more

628   complex visual processing tasks or the possible underlying mechanism that may support the

629   cross-modal integration of affective cues.

630   To address these issues, we used the FICE task to examine whether the concurrent

631   presentation of pleasant and unpleasant odorant cues affects the spatial distribution of

632   attentional resources towards happy face targets, and also compared self-reported measures of

633   anxiety to evaluate the extent to which these odors might alter the emotional state of the

634   participant. In the control condition, participants were significantly faster and less error prone

635   to detect a discrepant happy face target in a crowd of competing distracter faces, a finding

636   which is consistent with earlier work with this particular version of the FICE task

637   (Damjanovic et al. 2010). However, whilst this overall search advantage for happy faces was

638   observed in participants exposed to the unpleasant odor, it was abolished for participants

639   exposed to the pleasant odors. An initial consideration of these patterns may at first appear

640   difficult to reconcile with the category-specific facilitative effects reported in Leppänen and

641   Hietanen's emotion categorization study. However, further analyses taking on board the

642   recommendations made in Moessnang et al's (2011) work, reveals two important

643   characteristics on the time course effects of odors on the perception of happy facial

644   expressions: (i) pleasant odors facilitate the detection of happiness, but the benefits are short-

645   lived, and (ii) unpleasant odors help in the detection of happy faces, but only towards the end

646   of the visual search task.

647   The reversal of such phasic optimization effects from the two different odorants could

648   be accounted for in terms of the emotional state of the participant (Leppänen and Hietanen

649   2003). The significant differences between the pleasantness ratings for the odors were

650   maintained at the start of the experiment as well as towards the end, yet were matched for

651   their overall arousal, thus ruling out potential differences between the two experimental

652   contexts based in terms of differences in arousal. Furthermore, the odors produced differential

653   effects on the participants' levels of self-reported anxiety as measured by the STAI, such that

654   individuals who were exposed to the pleasant odor showed a reduction in their overall

655   anxiety, whilst participants exposed to the unpleasant odor demonstrated an increase in their

656   anxiety. Previous considerations of the participant's emotional state on facial expression

657   processing have either been made indirectly, in the form of potential mood congruency effects

658   as per Leppänen and Hietanen's (2003) work, or directly by collecting ratings from

659   participants about the extent of their current experiences of happiness and sadness (e.g.,

660   Niedenthal et al. 2000). For example, mood induction techniques leading to higher levels of

661   self-reported happiness or sadness resulted in participants perceiving the mood congruent

662   facial expressions for a longer time than control participants. Furthermore, identifying the

663   beneficial effects of certain odorants has predominantly focused on their anxiety reducing

664   capacities, rather than specifically identifying whether they improve an individual's own

665   happiness (e.g., Moss et al. 2008; Moss et al. 2010; Moss and Oliver, 2012; Zhou and Chen,

666   2009). In line with this work, emotional change in this study was operationalized in terms of

667   changes in self-reported state anxiety using the STAI, and whilst a reduction in anxiety would

668   be viewed as a positive feature of the odorant, it is not possible to establish from the present

669   data the extent to which pleasant odorants directly improved the participant's own levels of

670   happiness and any subsequent role this may have had in detecting happiness in the FICE task.

671   Taking into account the anxiety-modulating capacities of the odorants at the start of

672   the visual search task allows the priming capacities of the odorant to take effect, such that

673   participants performing the task with the concurrent presentation of a pleasant odorant, where

674   overall levels of anxiety are reduced, showed enhanced detection of happy face targets

675   relative to participants exposed to the unpleasant odorant. This particular pattern extends

676   Leppänen and Hietanen's work by demonstrating how positive changes within the participant,

677   as indexed in the current study in the form of reductions in self-reported anxiety, can facilitate

678   the perception of happy facial expressions during more complex attentional tasks. However,

679   the benefits of this reduction in anxiety on the perception of happiness is short-lived; towards

680   the end of the visual search task, the anxiety-modulating capacities of odors become

681   redundant in predicting the detection of happy targets. Surprisingly, unpleasant odors rather

682   than pleasant ones facilitate the detection of happy faces. We argue that the unpleasant odor

683   in the latter stage of the search process may serve to create a 'pop-out' environmental context

684   for the participants, directing their attention to environmentally incongruent emotional

685   information (i.e., happy faces) as they engage in avoidance based strategies in response to

686   inhaling the unpleasant odor (e.g., Boesveldt et al. 2010; Fannes et al. 2008). Thus, the

687   increase in the happiness superiority effect towards the end of the experiment and its overall

688   preservation in the unpleasant condition may result from successful negative affect repair

689   processes to offset this increase in anxiety and any such threat-related cognitive biases

690   associated with it (Byrne and Eysenck 1995). The fact that the unpleasant odor plays a more

691   salient role towards the end of the experiment may reflect differences in habituation patterns

692   between positive and negative odorant cues, with unpleasant odors taking considerably more

693   time to habituate, especially in experimental designs in which participants are explicitly

694   primed by rating an odorant for its level of unpleasantness (Dalton 1996; see also Seubert et

695   al. 2014).

696   Current explanations of the happiness superiority effect focus on the role of low level

697   perceptual advantages afforded by the 'toothy grin' in happy facial expressions (e.g., Calvo

698   and Marrero 2009; Calvo and Nummenmaa 2008; Horstmann et al. 2012). In the current

699   study, the facial expressions used to measure the happiness superiority effect were taken from

700   a database which included happy face exemplars with visually salient smiles, whilst the angry

701   face exemplars lacked a visually salient 'toothy snarl' equivalent feature (Horstmann et al.

702   2012; Lipp et al. 2009). As such, angry faces would have shared a greater degree of

703   perceptual overlap with neutral faces which also included this closed mouth feature,

704   materializing in increased error rates and response times for angry target-neutral distracter

705   crowds across the different conditions. The perceptual disadvantage of angry face targets over

706   happy targets was reduced when the surrounding crowd consisted of happy distracters, in

707   these conditions search performance was comparable to happy target-angry crowd search

708   conditions, thus resulting in a happiness superiority effect that was only found in the neutral

709   distracter context. In some instances, such interactions between target and distractors point

710   towards the involvement of an attentional disengagement mechanism, whereby response

711   times to detect happy targets is delayed when surrounded by angry distractor faces than

712   neutral faces (e.g., Damjanovic et al. 2014; Fox et al. 2000; Fox et al. 2001; Fox et al. 2002).

713   However, inferential analyses do not indicate that such a mechanism was involved in the

714   current visual search task, as participants' response times for happy target detection did not

715   differ significantly between the angry and neutral distractors.

716   Whilst the stability of the happiness superiority effect in the control condition would

717   have been compatible with such perceptual based accounts of emotion detection, the time

718   course analysis in the odor groups indicates that affective factors play a much more important

719   role (e.g., Becker et al. 2011). Our early socialization experiences (Bond and Siddle, 1996;

720   Kotsoni et al. 2001) may help to reinforce an expectancy bias towards positive stimuli

721   (Cacioppo and Gardner 1999; Cacioppo et al. 1999; Chipchase and Chapman 2007), yet the

722   phasic characteristics of participants' visual search times for happy facial expression targets,

723   reveal how easily this bias can be reset.

724   We propose that the emotional state of the participant plays an important role in the

725   perception of facial expression of happiness (e.g., Becker et al. 2011; Leppänen and Hietanen

726   2003; Niedenthal et al. 2000), supporting the cross-modal interaction of affective cues in a

727   time dependent manner (Walla 2008). Phasic analyses such as the ones performed in this

728   study not only serve to highlight the complexity of such cross-modal interactions, but may

729   also help pave the way for a better understanding on how affective vs perceptual accounts on

730   emotion detection can be disentangled. Furthermore, such phasic analyses prove to be

731   particularly helpful in reconciling differences between studies that would otherwise have been

732   masked if the analyses and interpretation of olfactory-visual processing focused exclusively

733   on overall reaction time performance (Moessnang et al. 2011).

734   Future efforts in validating affective accounts of the happiness superiority effect may

735   attempt to increase the arousal value of unpleasant odorants, for example by using human

736   chemosignals (e.g., Lundström et al. 2008; Zhou and Chen, 2009) to establish whether they

737   can open up the prioritization of threat specific cues. Thus, when environmental contexts

738   differ not only in their pleasantness value, but also in terms of their heightened arousal levels,

739   participants may then revert to searching for angry facial expressions instead (Becker et al.

740   2011; Chipchase and Chapman 2013; Lundqvist et al. 2013). Such systematic manipulations

741   of an odor's pleasantness and arousal values would also raise important implications for our

742   understanding of anxiety-based models of attention (e.g., Eysenck 1992; Eysenck et al. 2007),

743   and how this may differ functionally from a general expectancy bias favouring positive

744   information (e.g., Diener and Diener 1996; Fox 2013), for example. Indeed, it is worth noting

745   that the mean STAI (S) values for all three groups fell within the low-anxiety range reported

746   in visual search studies of this kind. For instance, some studies using a split-groups design

747   often pre-select individuals scoring high in trait anxiety (48 >), and have identified this

748   anxiety component as playing a more important role than high levels of state anxiety in

749   facilitating the detection of angry facial expressions (e.g., Byrne and Eysenck 1995). Other

750   studies have pre-screened participants on the basis of their state anxiety scores, allocating

751   scores above 40 on the STAI to the high anxious group and scores below 35 to the low

752   anxious group and have found this component of anxiety to play a stronger role in disrupting

753   threat disengagement attentional processes (e.g., Fox et al. 2001). Thus, future studies should

754   systematically consider both intrinsic and extrinsic facets of anxiety and their emotional

755   weighting in terms of the attentional capture of angry and happy facial expressions. Our work

756   indicates that the anxiety-modulating capacities of pleasant and unpleasant odors may serve as

757   a useful tool towards achieving this aim in sub-clinical populations (Krippl 2003).

758   Beyond the differences in attentional processing demands between the current study

759   and the work by Leppänen and Hietanen, other aspects of our methodology may explain why

760   the facilitative effects of the pleasant odor condition on the detection of happiness did not

761 materialize in the initial analysis of overall reaction time performance. For example, the

762 correspondence between the pleasantness value of the olfactory cues used by Leppänen and

763 Hietanen and the facial stimulus may have been more strongly primed than in the current

764 study given that participants were only required to make 'same' vs 'different' emotion

765 judgments on each experimental trial, in contrast to Leppänen and Hietanen's instructions

766 which required participants to categorize each trial using emotion labelled response keys.

767 Indeed, providing participants with emotion labels during the categorization task can also

768 influence the percentage of intrusion errors, that is the false categorization of emotional

769 expressions that were not presented in the target face such as perceiving sadness in an

770 ambiguous neutral-disgust face (Leleu et al. 2015). Thus, the presence of verbal cues may

771 have primed the cognitive system to search for a restricted set of emotion categories,

772 amplifying the perception of salient congruent expressions such as happiness, whilst blurring

773 the boundaries between less salient expressions such as disgust (Leleu et al. 2015).

774 Furthermore, unlike Leppänen and Hietanen's categorization task, the participants in the

775 current study performed over 200 visual search trials without a break. Whilst this may have

776 resulted in severe fatigue effects, no phasic effects were observed in the control condition,

777 indicating that this was not a particular cause for concern with the current study. Nevertheless,

778 the inclusion of a break in Leppänen and Hietanen's study may have helped to increase the

779 saliency of the pleasant odorant prime and its association with the happy facial expression in

780 the emotion categorization task, thus resulting in the overall category-specific facilitative

781 effects found.

782   In interpreting these results, some limitations must be considered. First, rather than

783 relying exclusively on self-report measures to determine functional olfactory sense, such

784 measures should be combined with a screening test such as the Sniffin' Sticks battery

785 (Hummel et al. 2001) to ensure all participants could perceive the applied odors to normative

786   levels. Furthermore, tighter control of adaptation mechanisms would help to provide a more

787   informative picture of odorant-specific reduction in sensitivity and perceived intensity during

788   odor exposure over the course of the experiment and its impact on cognitive performance

789   (Dalton et al. 1996; Ekman et al. 1967). The addition of post-experiment interviews to assess

790   each participant's awareness of the odors in their testing environment would also provide a

791   fruitful insight into the perceived intensity of each odorant in future research designs. For

792   example, adding questions with respect to the explicit ability to perceive the odor in the room

793   will help determine whether the contextual effects of odors on facial detection require explicit

794   awareness or can occur implicitly. Second, alternative self-report measures such as the

795   Positive and Negative Affect Schedule (PANAS; Watson et al. 1988) would provide a more

796   detailed account of the types of emotions experienced by participants in response to pleasant

797   and unpleasant odor contexts above and beyond their anxiety-modulating capacities and

798   provide a more comprehensive way to assess the category-specific basis of odour-emotion

799   perception interactions more fully.

800   Notwithstanding these limitations, our study shows that affective factors in the form of

801   changes in the emotional state of the participant play a more significant role in facilitating the

802   detection of target facial expressions of emotion than the perceptual salience of the face's

803   features (Becker et al. 2011; Calvo and Marrero 2009; Calvo and Nummenmaa 2008; Juth et

804   al. 2005). Indeed, contextual factors are a part of the multisensory nature of our emotional

805   interaction with others, and the dynamic nature of the emotional state of the participant needs

806   to play more of an active role in future research studies on attentional modulation, rather than

807   limiting such investigations to an individual differences framework (Frischen et al. 2008).

808   Along with music induction experiments (e.g., Garon et al. submitted; Rowe et al. 2007), our

809   study reveals how odors may provide another useful tool for researchers to examine the role

810   of affective factors in visual search tasks with emotionally salient stimuli.

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999

1000   Tables

1001   Table I

1002   *Mean STAI (S) pre and post test measures as a function of odor context. Standard Errors are*

1003   *presented in parentheses.*

1004

Measure	Context					
	Control		Pleasant		Unpleasant	
	Mean	(SE)	Mean	(SE)	Mean	(SE)
Pre-STAI (S)	33.56	(2.01)	36.78	(2.58)	32.00	(2.02)
Post-STAI (S)	35.50	(2.12)	31.72	(1.57)	35.56	(2.17)

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1007   Table II.

1008   Bootstrapped hierarchical mediation methods on the effect of odor type on the happiness

1009   superiority effect (block 1) as mediated through changes in self-reported state anxiety (block

1010   2) for the first quarter and last quarter of the visual search trials.

1011

	First quarter		Last quarter	
	B	*SE B*	*B*	*SE B*
Block 1				
Constant	164.31	39.22	65.15	37.88
Odor type	-93.64	47.87	122.34*	53.08
Block 2				
Constant	183.39	41.15	75.77	44.20
Odor type	-127.40*	51.10	103.55	67.96
STAI-CHANGE	3.77	3.59	2.10	3.61

1012   *Note.* Estimates are unstandardized; odor type is coded $0 =$ pleasant, $1 =$ unpleasant; 1,000

1013   bootstrap samples; * $< .05$.

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1024   **Figure Legends**

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1026   *Figure 1.* Visual search data for different displays. The left panels show mean reaction time

1027   and the right panels show mean error rates to detect the angry and happy facial expression

1028   targets against emotional (E) and neutral (N) distracters for the control (A), pleasant odor (B)

1029   and unpleasant odor (C) conditions. Error bars correspond to the standard errors of the mean

1030   of each condition individually.

1031

1032   *Figure 2.* Superiority index for happiness for the first and last 25% of search trials in

1033   milliseconds (ms) with emotional and neutral distractors across the three experimental

1034   contexts. A positive score indicates faster detection of happy over angry face targets on

1035   different display trials. Error bars correspond to the standard errors of the mean of each
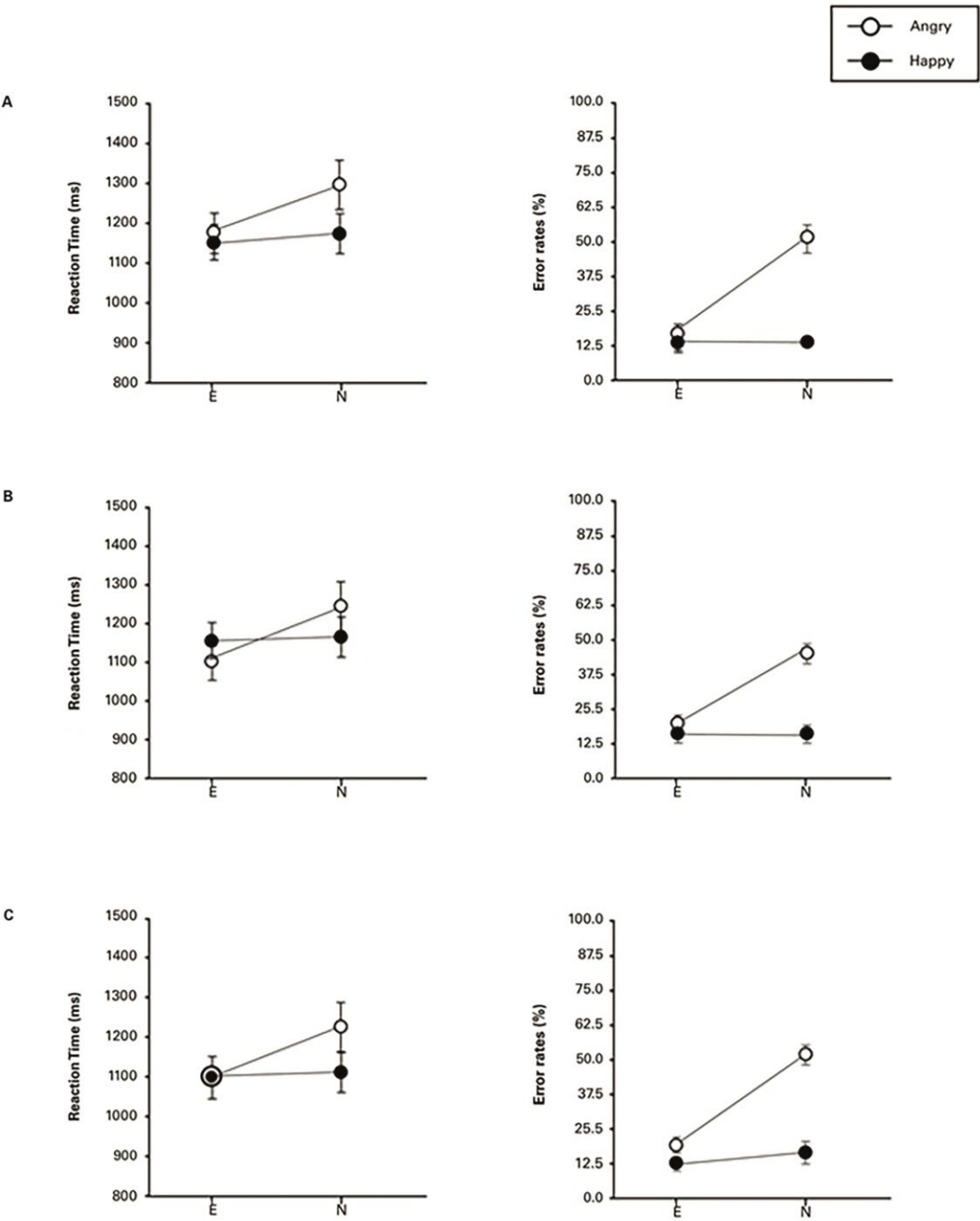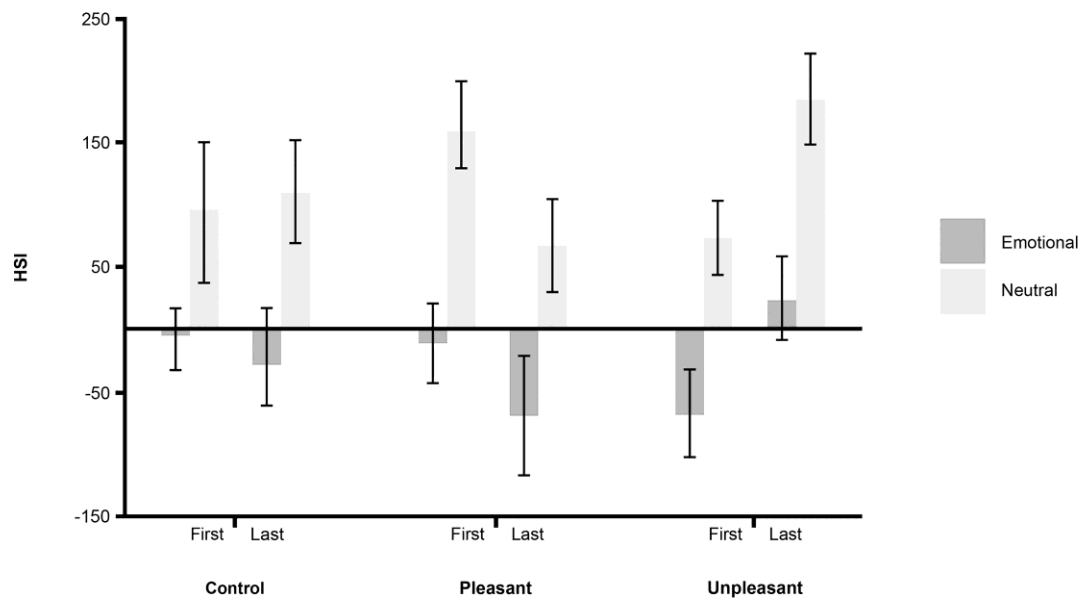
1036   condition individually.

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1041   Fig 1.

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1046   Fig 2.

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