ARTICLE IN PRESS

Physiology & Behavior xxx (xxxx) xxxx

Contents lists available at ScienceDirect

Physiology & Behavior

journal homepage: www.elsevier.com/locate/physbeh

Brief communication

Ethnic influences on the perceptual properties of human chemosignals

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ARTICLE INFO

Keywords:
Bias
Body odors
Ethnicity
Ingroup
Outgroup
Olfaction

ABSTRACT

Individuals of African and Caucasian descent show different chemical signatures in their body odors (BO). Does such biological difference have a perceptual correlate? We tested BO donors and raters of Afro-Portuguese (AP) and Caucasian (C) descent to investigate whether olfactory ratings reveal an ethnic bias and whether olfactory ethnic discrimination is possible. C (vs. AP) women rated the C BO as more pleasant, even when controlling for intensity. The C BO labelled as AP was rated as more intense by C raters. Although discriminability of ethnicity and sex is at chance, a nominal advantage for AP vs. C BO emerges.

1. Introduction

As the research in the past decade suggests, scientists are uncovering how body odors (BO) shape our social lives (for a review, [1,2]). BOs communicate to conspecifics evolutionarily relevant information which range from mating potential [3] to danger detection [4–12]). Humans use odor cues to probe the familiarity of an individual, discriminating whether they are a kin to an individual or not [13]. This is reflected at the level of perceptual judgements, in that the BO of kin is reported to be more pleasant than the BO of non-kin individuals [14]. However, odor cues associated with one individual's familiarity can also be communicated in relation to ancestral relatedness, such as in the case of ethnicity. Individuals of Caucasian and Asian descent show similar rhythmic EEG recordings when exposed to one's own BO and to the BOs of one's own ancestral ingroup [15]. Additionally, the analysis of chemical signatures of axillary odors [16] and human cerumen [17] suggests that several volatile organic compounds (VOCs) vary across ethnic groups and that individuals of African and Caucasian descent emit strong axillary BO, whose VOC composition and amount is markedly different across ethnicities.

But do these biological differences transfer at the perceptual level in a detectable manner? And if so, being aware of the ethnicity of the BO would bias the odor ratings in a stereotypical way (e.g., BO from the outgroup as unpleasant)? To directly put these questions to a test we have conducted a series of three studies including as BO donors and raters a group of individuals of African and Caucasian descent. In Experiment 1 and 2, we asked a group of women of Afro-Portuguese (henceforth, AP) and Caucasian (henceforth, C) descent to rate the perceptual features (i.e., intensity, pleasantness, familiarity and arousal) of the BO donated by women from their ingroup and their outgroup, when given no information about the nature of the odor and when instructed to believe that they were smelling either the BO of individuals of AP or C descent. In Experiment 3, we asked both AP and C men and women to donate their BO and recruited AP and C men and women raters to rate the BO along the previous perceptual dimensions. Additionally, we asked them to discriminate in a forced-choice task the ethnicity and the sex of the BO samples they smelled.

We hypothesized that an ingroup ethnic bias appears in the pleasantness and familiarity (possibly in the arousal) ratings, with raters preferring the (less arousing) BO of individuals in the ingroup vs. outgroup. We expect this olfactory ethnic bias to be independent of the BO's intensity and to be more evident when raters are primed with information regarding the ethnic provenance of the BO. Besides predicting to confirm that the BO of men is more intense and less pleasant

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https://doi.org/10.1016/j.physbeh.2019.05.005
Received 17 November 2018; Received in revised form 3 May 2019; Accepted 7 May 2019
0031-9384/

Please cite this article as: Valentina Parma, et al., Physiology & Behavior, https://doi.org/10.1016/j.physbeh.2019.05.005

of that of women across ethnicities, we anticipate the discriminability of ethnicity to be achievable, supporting the idea of the possible existence of an unconscious olfactory ethnic bias.

2. Materials and methods

The research protocol was approved by the Ethics Committee of the University of Aveiro (Portugal) and followed the guidelines of the Declaration of Helsinki, as well as the standards of the American Psychological Association. All the donors and recipients provided written informed consent to participate in the study and were explicitly informed that they could drop out of the study anytime, without any consequences or additional explanations.

2.1. Participants

In Experiment 1 and 2, 24 young women, 12 of AP descent and 12 of C descent were recruited as BO donors. Fifty-eight women (26 AP) rated 12 trials per odor condition, namely BO of AP descent, C descent, and no odor (see below for details on the stimuli). In Experiment 3, a group of 47 donors [23 AP (11F); 24 C (12F)] was recruited. All participants self-reported their race/ethnicity by choosing one or multiple appropriate categories among Asian, Black, Latino, White. Participants marking Asian, Latino or multiple categories were excluded. Seventy-one recipients [31 AP (11F); 40C (18F)] were exposed to female and male BO from the two ethnicities. All participants age ranged from 18 to 37 years old (M = 22.99, SD = 4.27) and no significant differences across ethnicity and sex groups within each experiment nor across experiments were revealed (all ps > 0.05). For all the experiments, donors were asked to shave their armpits 7 days prior to BO collection. Six AP and four C women were on hormonal birth control, but their data were included in the analyses because their performance was in line with the rest of their respective groups.

2.2. BO stimuli

For all experiments, the donors and the raters were non-smokers, medication free and did not self-report to have any physical, metabolic or mental disease (as in [4,18]). They were instructed to refrain from using fragrant hygiene products, drinking alcohol and eating spicy foods 24 h before the sampling in order to avoid alterations of their natural BO (as in [4,18]). As in [18], the BO of the donors was collected for 4 consecutive hours on nursing pads sewn into the armpits of t-shirts previously washed with odorless detergent; all sampling was performed in the morning period, i.e., before lunch in a class environment, during a non-stressful period (i.e. without any type of evaluation). The pads, always handled with odorless surgical gloves, were collected from each armpit, cut into four quadrants and frozen at $-20\,^{\circ}$C (as in [18]). After having been thawed for one hour prior to testing, two pad quadrants from different donors belonging to the same ethnic and sex group were disposed along the walls of wide-mouthed glass jars with lids and they were subsequently presented to the recipients. Although a previous study [19] has observed that composite body odors show similar hedonic perceptual properties as individual odors, in the present study we used two quadrants with different donors, as to reduce the effects of individual variation, given that participants were faced with an ethnic and sex discrimination task.

2.3. Procedures

In all experiments, raters were asked to smell the BO contained in one jar at a time and to rate on a 10-cm visual analogue scale (VAS) the intensity, pleasantness, familiarity, and arousal (intended as physiological activation) of each of the BO presented. In Experiment 1, no instruction was given regarding the nature of the BO. In Experiment 2, raters were primed with the verbal instruction that the BO were collected from individuals of AP or C descent. To avoid priming effects they always smelled the no odor condition first and subsequently the congruency of the BO to their own ethnicity was randomized. In both experiments, each odor condition was smelled for 12 times. In Experiment 3, raters were asked to rate the BO on the abovementioned VASs without being provided with any instruction as to the nature of the odor they would smell. In order to remove potential odor dilution effects due to resampling, each odor condition was smelled 4 times per participant. Subsequently, raters were asked to discriminate the BO based on ethnicity and sex in a two-alternative forced-choice task.

2.4. Data analysis

Data was analyzed using R (version 3.3.2). We performed separate linear mixed models (LMMs) to analyze the rated intensity, pleasantness, familiarity, and arousal of the raters' reports across the different BO conditions and instructions, whenever provided. The LMMs used for these analyses included the self-reports as dependent variable, the odor condition and the type of instruction (if present) as the fixed, within-subject factors and the Subject ID as a random factor. To test specific hypotheses (e.g., pleasantness in Experiment 1) or when singularity issues were encountered, we used planned contrasts to explore the effects of interest. ANOVA results were retrieved from the LMM models via the ANOVA function. Post-hoc contrasts were run via the function glht of the *multcomp* package [20], following the Tukey method and the Bonferroni correction to adjust for multiple comparisons. Results reported include the mean (M) and standard error (SE). Receiver operating characteristic (ROC) curve analysis was performed to determine the classification accuracy of the ability of participants to recognize the target BO. Such analysis was computed via the *klaR* package [21]. Results are visualized via the ROCR package [22]. ROC curves plot the performance of binary classifiers by graphing true positive rates versus false positive rates (ranging from 0 to 1). The area under the curve (AUC) is the space in the graph that appears below each ROC curve, and it is a value between 0 and 1. The closer the value of AUC is to 1, the better the performance of the classification model. In all instances, the significance level is set at $p < .05$.

3. Results and discussion

3.1. Experiment 1

Table 1 shows the findings resulting from the LLM *Rating~Odor Condition*Rater Ethnicity + (1| Subject)* computed to test whether ethnic differences transfer at the perceptual level. When smelling the C BO, women of C descent find the BO more pleasant (and arousing -exploratory analysis) as compared to AP women. No significant differences were reported for familiarity (Fig. 1). However, raters reported that the intensity of the no odor condition was significantly lower than that of the AP and C BO (Fig. 1). Based on the idea that a general increase in the intensity of an olfactory stimulus corresponds to a reduction in its pleasantness, a new analysis was run with intensity as a covariate to verify whether the pleasantness result across C and AP women raters could be driven by a quantitative difference in chemicals rather than a qualitative one. Indeed, the pleasantness effects remained, indicating that a change in features other than the amount of chemicals in the BO seems to drive the pleasantness report recorded in C vs. AP raters.

To verify whether the overt knowledge of the ethnic nature of the BO would modulate this perceptual report, we run Experiment 2 on the same set of participants.

3.2. Experiment 2

Due to a singularity issue, it was not possible to run the full LLM *Rating~Odor Condition*Rater Ethnicity*Instruction + (1| Subject)*.

Table 1
Results of the LLM models for Experiment 1. numDF = degrees of freedom numerator; denDF = degrees of freedom denominator.

		numDF	denDF	F-value	*p*-Value
Intensity	(Intercept)	1	634	269.50	< 0.0001
	BO ethnicity	2	634	17.81	< 0.0001
	Rater ethnicity	1	56	1.67	0.20
	BO ethnicity:Rater ethnicity	2	634	0.04	0.97
Pleasantness	(Intercept)	1	634	155.46	< 0.0001
	BO ethnicity	2	634	16.39	< 0.0001
	Rater ethnicity	1	56	6.71	0.01
	BO ethnicity:Rater ethnicity	2	634	2.87	0.06
Familiarity	(Intercept)	1	634	114.65	< 0.0001
	BO ethnicity	2	634	1.62	0.20
	Rater ethnicity	1	56	0.90	0.35
	BO ethnicity:Rater ethnicity	2	634	0.17	0.84
Arousal	(Intercept)	1	634	209.21	< 0.0001
	BO ethnicity	2	634	4.11	0.02
	Rater ethnicity	1	56	4.59	0.04
	BO ethnicity:Rater ethnicity	2	634	2.09	0.12

Instead, we assessed via planned contrasts if associating a BO with an ethnic label would bias the odor ratings in a stereotypical way. Such tests (depicted in Fig. 2) revealed that no significant effect of instruction on the rating of the AP and C BO was reported by either the AP or the C raters. This suggests that explicitly triggering an ethnicity bias had no effect on the olfactory ratings that these women raters provided. Here, the C BO associated with the label AP was rated as more intense (and marginally more arousing) by C raters than AP raters (Fig. 2, red lines). However, no difference was retrieved when comparing the ratings of the same BO when associated to the AP or C labels in either the C raters or the AP raters. A lack of significance in the pleasantness ratings suggests that when overtly aware of the presence of the BO of a person from the ingroup and the outgroup, C raters refrain from providing any explicit valence judgements.

All in all, these findings suggest that female raters - those considered the most sensitive smeller (e.g. [23],) - are able to report on BO-mediated ethnicity only by using a pleasantness/arousal perceptual strategy and that their odor judgements are not significantly influenced by the cognitive triggering of the ethnicity bias. Based on this evidence, two questions arise: i) is the BO collected from women not strong enough to produce differences that can be accessed explicitly? Indeed, since men have larger apocrine glands than women they are usually recruited as BO donors [24]; ii) can the ethnicity information be less salient than other social signals simultaneously embedded in the same BO (e.g., sex)? It has indeed be demonstrated that women and men can focus on different social messages within the same BO [25]. We run Experiment 3 to provide insights about these issues.

3.3. Experiment 3

All LLMs had the following structure *Rating~Odor Condition*Rater Ethnicity*Rater Sex + (1| Subject)* and detailed statistics can be found in Table 2. The analysis of intensity ratings revealed that overall male BO are perceived as more intense than female BO, but this is particularly true in the case of the AP BO. Pleasantness ratings suggest that overall BO collected from women are more pleasant than those collected from men. This finding is in line with the well-established, inverse relationship between odor intensity and pleasantness [26], with the evidence linking women's smaller apocrine glands with a less concentrated BO.

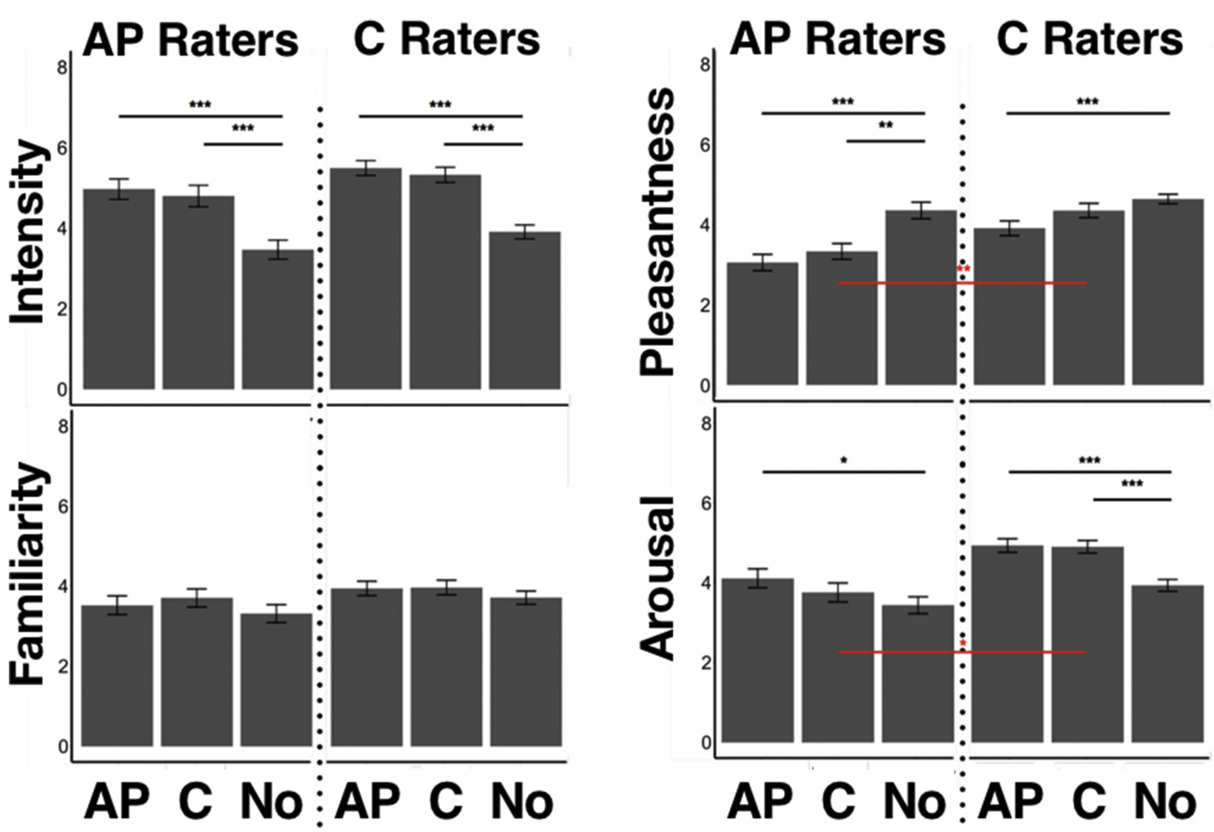

Fig. 1. Subjective BO ratings for Intensity (top, left), Pleasantness (top, right), Familiarity (bottom, left), and Arousal (bottom, right). AP = Afro-Portuguese, C = Caucasian, No = no odor condition. The left side of each graph reports the ratings from the AP raters and the right side of each graph reports the ratings from the C raters. In red, the comparisons between groups. *$p < .05$; **$p < .01$; ***$p < .001$. Bar = standard error of the mean (SEM). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

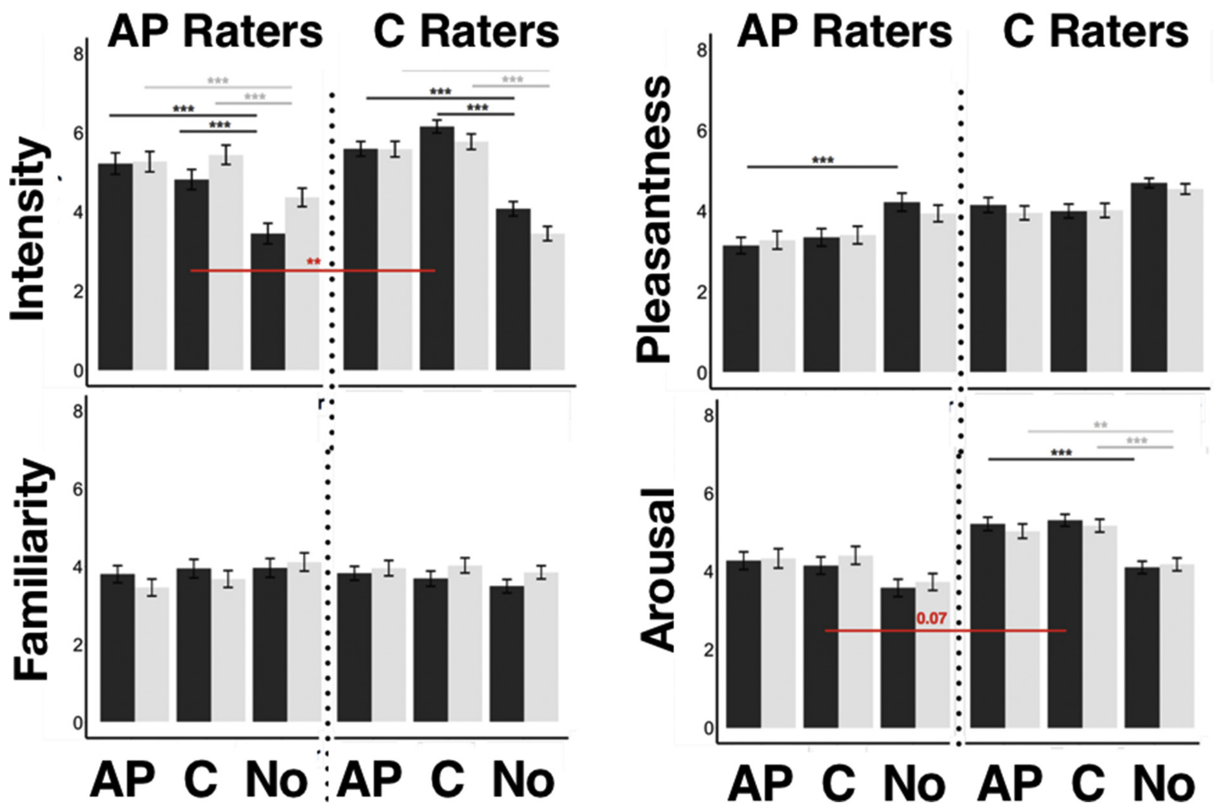

Fig. 2. Subjective BO ratings for Intensity (top, left), Pleasantness (top, right), Familiarity (bottom, left), and Arousal (bottom, right). AP = Afro-Portuguese, C = Caucasian, No = no odor condition. The left side of each graph reports the ratings from the AP raters and the right side of each graph reports the ratings from the C raters. Light grey bars refer to the ratings performed under BO = C instructions, whereas black bars refer to the ratings performed under BO=AP instructions. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$. Bar = standard error of the mean (SEM).

No pleasantness effect based on the ingroup/outgroup is revealed.

Familiarity ratings showed that men (but not women) across ethnicities rate female odor of the ingroup as more familiar. To justify this sexual asymmetry, we speculate that this may be related – although non linearly [27] - to men being more attuned to BO-dependent sex information rather than women [28].

In line with the intensity ratings, the arousal ratings reveal that all raters find the male AP BO as more arousing than the male C BO. This is consistent with the evidence produced by Prokop-Prigge and colleagues [16], which points to higher levels of axillary odorants compared in donors of African descent.

When assessing the ability to discriminate the ethnicity and sex embedded in the BO, it appears evident that raters, irrespective of their ethnic background, are not able to correctly discriminate the target BO in a reliable manner (max AUC = 0.63, p value against chance = 0.06). However, at least nominally, we can observe that it is relatively easier to discriminate the AP BO as compared to the C BO, the male BO as compared to the female BO and this pattern is maintained even when considering all four categories together, with higher discrimination rates for the AP male (AUC = 0.63), AP female (AUC = 0.58), C male (AUC = 0.57) and C female BO (AUC = 0.47). Considering that these findings are moderately underpowered (power range: 50–78%), interpretation requires caution (Fig. 3).

Altogether these results seem to reveal that raters, both men and women, may be able to discriminate ethnicity based on BO signals, in particular using a pleasantness strategy. When directly compared in a discrimination test, a nominal advantage in discriminating male and female BO from AP donors vs. male and female BO from C donors emerges. We suggest that ethnicity information may be extracted via the BO. In line with our hypotheses, differences related to ethnicity – likely genetic, although we cannot exclude diet- and hygiene-related influences – can transfer at the perceptual level. We also extend this literature to the behavioral level, revealing that judgments on odor intensity, pleasantness, familiarity and arousal may represent the behavioral correlates of the differences at the level of the chemical signatures of ethnicity. However, being aware of the ethnicity of the BO does not seem to bias the odor ratings in a stereotypical way. Whether such reduction in stereotype vulnerability is dependent on the ethnic homogenity of donors and recipients [29] as well as a clear hierarchy in the discriminability of individual features of the same BO requires further investigation. These results start uncovering the presence of a possible olfactory-based ethnic bias (see [30] for insights on Asian-Caucasian relationships). As demonstrated in other senses [31], it is important to understand the impact of such bias in intra-and inter-groups interactions. In line with [32], further studies should assess the role of olfactory-based ethnicity as a trigger of the behavioral immune system, a set of psychological mechanisms evolved to detect the presence of real and perceived pathogens and to promote their avoidance [33,34] as well as the relevance of ethnic differences in the context of human mate choices [3].

Funding

No funding to disclose.

Declaration of conflicting interests

The authors declare no conflicts of interest with respect to the authorship or the publication of this article.

Table 2
Results of the LLM models for Experiment 3. numDF = degrees of freedom numerator; denDF = degrees of freedom denominator.

		numDF	denDF	F-value	p-value
Intensity	(Intercept)	1	555	123.88	< 0.0001
	BO ethnicity	1	555	2.31	0.13
	Rater ethnicity	1	77	5.27	0.02
	BO sex	1	555	16.61	< 0.0001
	Rater sex	1	77	0.25	0.62
	BO ehnicity:Rater ethnicity	1	555	5.23	0.02
	BO ethnicity:BO sex	1	555	2.31	0.13
	Rater ethnicity:BO sex	1	555	1.53	0.22
	BO ethnicity:Rater sex	1	555	1.06	0.30
	Rater ethnicity:Rater sex	1	77	0.29	0.59
	BO sex:Rater sex	1	555	0.00	0.99
	BO ethnicity:Rater ethnicity:BO sex	1	555	0.79	0.37
	BO ethnicity:Rater ethnicity:Rater sex	1	555	0.62	0.43
	BO ethnicity:BO sex:Rater sex	1	555	0.10	0.75
	Rater ethnicity:BO sex:Rater sex	1	555	1.49	0.22
	BO ethnicity:Rater ethnicity:BO sex:Rater sex	1	555	0.51	0.48
Pleasantness	(Intercept)	1	555	42.89	< 0.0001
	BO ethnicity	1	555	5.52	0.02
	Rater ethnicity	1	77	0.98	0.32
	BO sex	1	555	9.62	< 0.0001
	Rater sex	1	77	0.00	0.95
	BO ethnicity:Rater ethnicity	1	555	11.95	< 0.0001
	BO ethnicity:BO sex	1	555	0.39	0.53
	Rater ethnicity:BO sex	1	555	0.08	0.78
	BO ethnicity:Rater sex	1	555	11.59	< 0.0001
	Rater ethnicity:Rater sex	1	77	0.33	0.57
	BO sex:Rater sex	1	555	0.00	0.95
	BO ethnicity:Rater ethnicity:BO sex	1	555	0.49	0.49
	BO ethnicity:Rater ethnicity:Rater sex	1	555	3.88	0.05
	BO ethnicity:BO sex:Rater sex	1	555	1.17	0.28
	Rater ethnicity:BO sex:Rater sex	1	555	0.80	0.37
	BO ethnicity:Rater ethnicity:BO sex:Rater sex	1	555	0.00	0.97
Familiarity	(Intercept)	1	555	55.93	< 0.0001
	BO ehnicity	1	555	7.73	0.01
	Rater ethnicity	1	77	0.57	0.45
	BO sex	1	555	3.46	0.06
	Rater sex	1	77	0.02	0.89
	BO ethnicity:Rater ethnicity	1	555	1.39	0.24
	BO ethnicity:BO sex	1	555	0.01	0.94
	Rater ethnicity:BO sex	1	555	5.04	0.03
	BO ethnicity:Rater sex	1	555	1.65	0.20
	Rater ethnicity:Rater sex	1	77	0.07	0.79
	BO sex:Rater sex	1	555	2.94	0.09
	BO ethnicity:Rater ethnicity:BO sex	1	555	1.81	0.18
	BO ethnicity:Rater ethnicity:Rater sex	1	555	0.46	0.50
	BO ethnicity:BO sex:Rater sex	1	555	0.27	0.60
	Rater ethnicity:BO sex:Rater sex	1	555	2.42	0.12
	BO ethnicity:Rater ethnicity:BO sex:Rater sex	1	555	1.95	0.16

Table 2 (*continued*)

		numDF	denDF	F-value	p-value
Arousal	(Intercept)	1	555	56.15	< 0.0001
	BO ethnicity	1	555	3.77	0.05
	Rater ethnicity	1	77	0.07	0.79
	BO sex	1	555	1.00	0.32
	Rater sex	1	77	0.47	0.50
	BO ethnicity:Rater ethnicity	1	555	0.04	0.84
	BO ethnicity:BO sex	1	555	0.69	0.41
	Rater ethnicity:BO sex	1	555	0.87	0.35
	BO ethnicity:Rater sex	1	555	0.74	0.39
	Rater ethnicity:Rater sex	1	77	1.40	0.24
	BO sex:Rater sex	1	555	3.25	0.07
	BO ethnicity:Rater ethnicity:BO sex	1	555	0.84	0.36
	BO ethnicity:Rater ethnicity:Rater sex	1	555	0.17	0.68
	BO ethnicity:BO sex:Rater sex	1	555	1.08	0.30
	Rater ethnicity:BO sex:Rater sex	1	555	1.15	0.28
	BO ethnicity:Rater ethnicity:BO sex:Rater sex	1	555	2.37	0.12

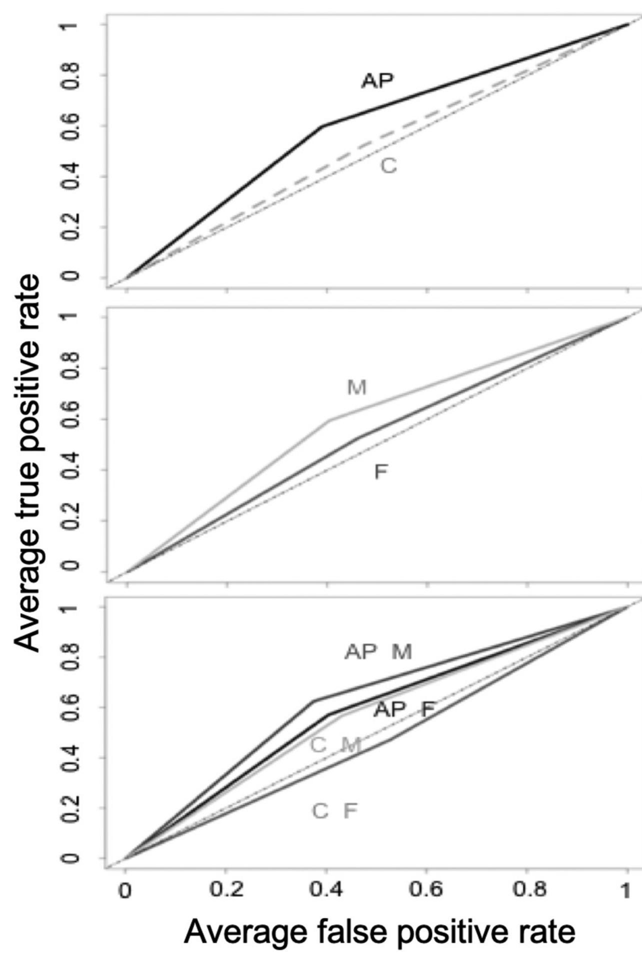

Fig. 3. Receiver operating characteristic (ROC) curve analysis related to the classification accuracy of the ability of Afro-Portuguese male (AP M), Afro-Portuguese female (AP F), Caucasian male (C M), Caucasian female (C F) raters to correctly identify the target BO. The closer the line is to the top left corner, the better the identification performance. The dashed diagonal represents identification at chance level.

Acknowledgements

The data and experimental materials are available on request. We thank Carla Silva for her contribution to data collection. This research was supported by doctoral grants from FCT—Fundação para a Ciência e a Tecnologia through the POPH/FSE Program [SFRH/BD/85376/2012 to J.F. and SFRH/BD/111238/2015 to M.R.], FEDER grants to SCS through the operation POCI-01-0145-FEDER-007746 and FCOMP-01-0124-FEDER-029587 funded by the Programa Operacional Competitividade e Internacionalização— COMPETE2020, and by National Funds within CINTESIS, R&D Unit [FCT PTDC/MHC-PCN/4842/2012]. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

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