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OBSERVATION

Revisiting the Link Between Horizontal Tuning and Face Processing Ability With Independent Measures

Justin Duncan
University of Quebec in Montreal and University of Quebec in Outaouais

Jessica Royer
McGill University and University of Quebec in Outaouais

Gabrielle Dugas, Caroline Blais, and Daniel Fiset
University of Quebec in Outaouais

In recent years, horizontal spatial information has received attention for its role in face perception. One study, for instance, has reported an association between horizontal tuning for faces and face identification ability measured within the same task. A possible consequence of this is that the correlation could have been overestimated. In the present study, we wanted to reexamine this question. We first measured face processing ability on the Cambridge Face Memory Test+, the Cambridge Face Perception Test, and the Glasgow Face Matching Test. A single ability score was extracted using a principal components analysis. In a separate task, participants also completed an identification task in which faces were randomly filtered on a trial basis using orientation bubbles. This task allowed the extraction of individual orientation profiles and horizontal tuning scores for faces. We then measured the association between horizontal tuning for faces and the face-processing ability score and observed a significant positive correlation. Importantly, this relation could not be accounted for by other factors such as object-processing ability, horizontal tuning for cars, or greater sensitivity to horizontal gratings. Our data give further credence to the hypothesis that horizontal facial structure plays a crucial role in face processing.

Public Significance Statement

In recent years, there has been a growing interest for spatial orientations and especially horizontal structure in the face processing literature. Here we measured the link between individual differences in face-processing ability and selective utilization of horizontal face structure and found a significant association between the two variables. These results are important because they further our understanding of fundamental face-processing mechanisms and possibly open the door to clinical applications with individuals for whom face recognition poses a challenge, such as through perceptual training based on horizontal spatial information.

Keywords: bubbles, face perception, psychophysics, orientation

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A variety of theories have been proposed to explain how the visual system makes sense of the face stimulus. Holistic processing (e.g., Maurer, Grand, & Mondloch, 2002; Richler, Palmeri, & Gauthier, 2012; Rossion, 2008; Yin, 1969) and its link with individual differences in face processing skills (e.g., DeGutis, Wilmer, Mercado, & Cohan, 2013; Richler, Cheung, & Gauthier, 2011), for example, has been a primary focus of much of the past decades.

However, many studies suggest that humans rely on a restrained subset of the available information to recognize faces. In the image domain, experiments have shown that face recognition is largely driven by the eyes (Butler, Blais, Gosselin, Bub, & Fiset, 2010; Gold, Mundy, & Tjan, 2012; Gosselin & Schyns, 2001; Sekuler, Gaspar, Gold, & Bennett, 2004), that differences in face-processing ability are linked with utilization of this feature (Royer et al., 2018; Tardif et al., 2019), and that prosopagnosia comes from an inability to process this face feature (Bukach, Le Grand, Kaiser, Bub, & Tanaka, 2008; Caldara et al., 2005; Fiset et al., 2017; Pancaroglu et al., 2016;

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Justin Duncan, Department of Psychology, University of Quebec in Montreal, and Department of Psychoeducaton and Psychology, University of Quebec in Outaouais; Jessica Royer, Department of Neuroscience, McGill University, and Department of Psychoeducaton and Psychology, University of Quebec in Outaouais; Gabrielle Dugas, Caroline Blais, and Daniel Fiset, Department of Psychoeducaton and Psychology, University of Quebec in Outaouais.

Correspondence concerning this article should be addressed to Daniel Fiset, Department of Psychoeducaton and Psychology, University of Quebec in Outaouais, C.P. 1250, Succursale Hull, Gatineau (Québec), Canada J8X3X7. E-mail: daniel.fiset@uqo.ca

Rossion, Kaiser, Bub, & Tanaka, 2009). In the spatial frequency domain, face identification has been shown to rest on a band of approximately 8–20 cycles per face (Gaspar, Sekuler, & Bennett, 2008; Näsänen, 1999; Royer et al., 2017; Tardif et al., 2017; Willenbockel et al., 2010), largely associated with internal facial features (Keil, 2009).

Recently spatial orientations have garnered attention for the role horizontal information appears to play in various aspects of face processing, such as detection (Balas, Schmidt, & Saville, 2015), identification (Dakin & Watt, 2009; Goffaux & Dakin, 2010; Goffaux, Duecker, Hausfeld, Schiltz, & Goebel, 2016; Goffaux & Greenwood, 2016; Goffaux & Schiltz, 2015; Pachai, Sekuler, Bennett, Schyns, & Ramon, 2017), and emotional facial expression recognition (Balas & Huynh, 2015; Balas, Huynh, Saville, & Schmidt, 2015; Duncan et al., 2017; Huynh & Balas, 2014; Yu, Chai, & Chung, 2018). Horizontal information also supports behavioral signatures of face-processing specialization, such as the face inversion effect (Goffaux et al., 2010, 2016; Pachai, Sekuler, & Bennett, 2013). Interestingly, this information is object based, and a 90° image rotation will induce a shift toward the vertical image—that is, horizontal facial—structure (Huynh et al., 2014). This is in line with recent evidence suggesting that orientation tuning for faces is in fact flexible and depends on task demands (Goffaux, 2019).

If horizontal facial information is linked to recognition, then we should observe an association between face-processing ability and use of this information. As it stands, one study has addressed the question (Pachai et al., 2013; see also, for facial expressions, Duncan et al., 2017). However, face-processing ability and horizontal tuning for faces were not measured independently. Indeed, participants completed an identification task in which orientation-filtered (eight bands) or unfiltered (white) noise was added to stimuli, and a noise-masking threshold was calculated separately for each noise condition. Individual horizontal tuning scores were then extracted by calculating the slope of the regression lines separating the horizontal and vertical noise-masking thresholds, and identification ability was taken as the white noise–masking threshold. A moderate correlation was observed between these measures, meaning that participants who performed better in the white noise condition used horizontal information more selectively. Although these results are important, one cannot help but notice the potential for circularity. Indeed, subjects who make the best use of diagnostic information in a task will also perform better in this very same task, and there will be more overlap in variance if diagnostic information utilization and ability are measured using the same task than if they are measured using different tasks. For this reason, it is possible that the correlation observed by Pachai and colleagues is somewhat inflated (the argument also applies to the study of Duncan et al., 2017), and it is of great theoretical importance to verify that this link generalizes across other face-processing tasks.

We therefore administered four face-processing tasks in this study. Three were validated measures of individual differences in face processing, from which we extracted a single ability score. The fourth task was designed to measure individual orientation profiles and horizontal tuning for faces using orientation bubbles. The link between horizontal tuning for faces and face-processing ability was then verified. Two measures of object processing, and one measure of low-level image processing, were also included (see online supplemental materials, *Results*, and *Discussion*) in a partial correlation analysis to serve as control measures.

Method

Participants

Thirty-seven subjects aged between 18 and 40 years ($M = 25.72$ years old, $SD = 5.67$) were recruited at the Université du Québec en Outaouais to complete a battery of tests (below; see also online supplemental materials). Some of these were outside the scope of the present paper and the results are thus not reported here. A power analysis using G-power (Faul, Erdfelder, Buchner, & Lang, 2009) revealed that this study was adequately powered to detect a correlation of $r = .4$ with a power of 0.8 and Type I error probability of 0.05. Compared with previous results, this value was more conservative to account for the fact that we measured horizontal tuning for faces and face-processing ability independently and also because it was closer to other results (Royer et al., 2018). All participants had normal or corrected-to-normal vision and received financial compensation for their participation. This experiment was conducted in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and received approval from the university's research ethics committee.

Apparatus

The experiments were conducted on MacMini computers. Stimuli were displayed on a 24-in BenQ LCD monitor with 1920 × 1080 resolution and evenly distributed luminance levels. Participants sat in a dark room and a chin rest was used to maintain a 69-cm viewing distance.

Face-Processing Ability

Three tasks were completed: the Cambridge Face Memory Test+ (CFMT+; Duchaine & Nakayama, 2006; Russell, Duchaine, & Nakayama, 2009), the Cambridge Face Perception Test (CFPT; Duchaine, Germine, & Nakayama, 2007), and the Glasgow Face Matching Test–short version (GFMT; Burton, White, & McNeill, 2010). Cambridge tests were programmed in Java, the GFMT in Matlab (Natick, MA).

Orientation Bubbles Task

The images portrayed 10 individual faces (half female) displaying a neutral expression (Willenbockel et al., 2010). Luminance histograms and spatial frequency spectra were equalized with the SHINE toolbox (Willenbockel et al., 2010) to reduce low-level interstimuli variance. The images were downscaled to 512 × 512 pixels (7°), and an oval that blended with the gray monitor background (66.33 cd/m^2) was applied to hide the facial contour and external features (Figure 1a). Faces were spatially aligned on the positions of the eyes, nose, and mouth, using translation, rotation, and scaling.

To create an orientation-bubblized stimulus, a base image (Figure 1a) was first submitted to the Fast Fourier Transform algorithm, and its quadrants were shifted to reveal its orientation

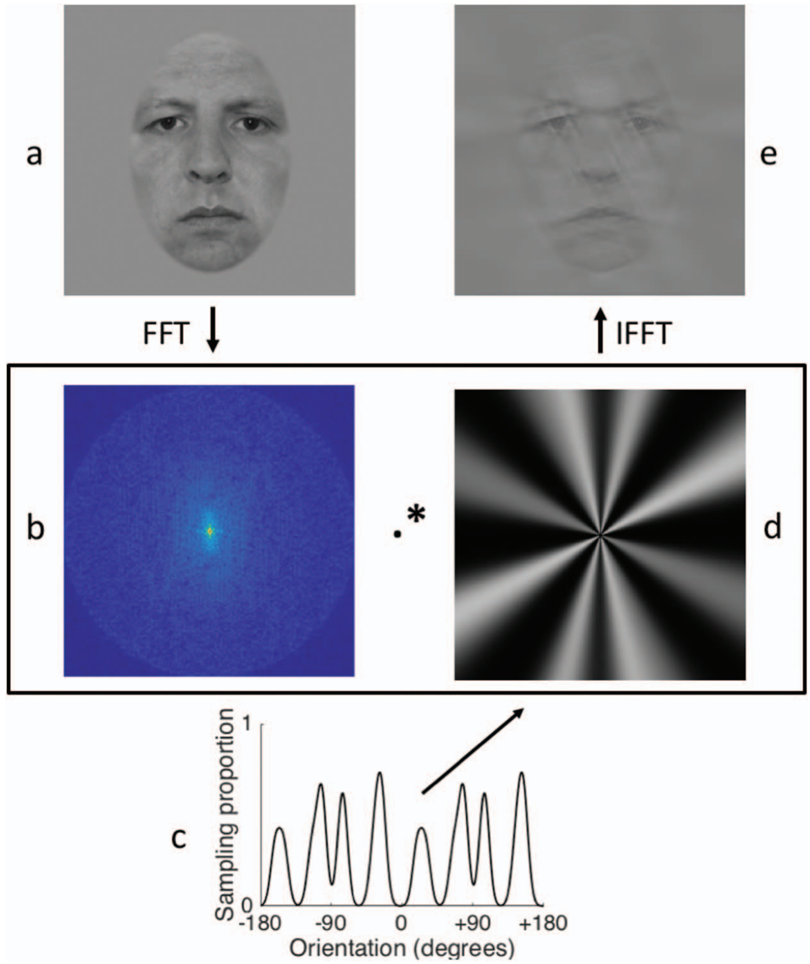

Figure 1. Orientation bubbles procedure. See text for description. The face shown is that of author Daniel Fiset. See the online article for the color version of this figure.

content (Figure 1b). An orientation sampling vector was then created by summing 10 pairs of symmetrical Von Mises orientation samples, or orientation bubbles (Figure 1c). This circular distribution ranges from $-180°$ to $+ 180°$ and has two parameters, μ (peak) and κ (width, equal to 92.9, or about 14° [Goffaux et al., 2010]). One bubble consisted of two Von Mises, one with parameter μ_i, and the other with parameter $\mu_i + 180°$. The μ_i parameters (i equal 1 to 10) were randomly drawn with replacement from a rectangular distribution of orientations.

An orientation sampling matrix (Figure 1d) of dimension 512 × 512 pixels was created by applying the orientation sampling vector to an orientation matrix equal to $\tan^{-1}([y.\ 255]/[x - 255])$, where y and x correspond to the columns and rows of the matrix. Sampling proportion ranged from 0 to 1. The orientation sampling matrix was then applied to the image orientation content, producing an orientation-bubblized Fourier spectrum, and the product was brought back to the image domain with the inverse Fast Fourier Transform (Figure 1e).

The task consisted of a 10-alternative forced choice identification procedure sequenced into blocks of 100 trials each and was programmed in Matlab using custom code and the psychophysics toolbox (Brainard, 1997; Pelli, 1997). A trial began with a central fixation cross that was displayed for 500 ms. Then a stimulus appeared in the center of the monitor and remained visible until a response was entered, using one of 10 preallocated keys on the computer keyboard (i.e., one per identity).

Participants first performed two practice versions of this task: noiseless broadband and noisy broadband. In the noiseless practice, participants completed as many blocks as needed to achieve 90% correct responses ($M = 2$ blocks, $SD = 0.97$). Then participants completed one noisy practice block in which white noise was added to each face stimulus. This was done so that participants could familiarize themselves with the noisy aspect of stimuli.

Finally, participants completed six experimental blocks with orientation-bubblized stimuli to which white noise was added. In both the noisy practice and experimental task, difficulty was manipulated on a trial basis so that approximately 55% correct responses (halfway between floor [10%] and ceiling [100%]) were maintained. Specifically, we used QUEST (Watson & Pelli, 1983) to determine the proportion p, comprised between 0 and 1, of the broadband (noisy practice) or orientation-bubblized (experiment) image i that was needed. To this, a proportion $1 - p$ of white noise w was added. Thus, the final stimulus can be expressed as $ip + w(1 - p)$, and its signal to noise ratio (SNR) can be expressed as $p/(1 - p)$.

Results and Discussion

Participants needed an average SNR of 2.46 ($SD = 0.94$; 95% confidence interval CI [2.15, 2.78]) to maintain near 55% correct responses in the orientation bubbles task; there was no floor effect and all could perform the task with some noise. It must be stated that orientation bubbles reduce the image RMS contrast (see Figure 1, a and e). For example, the maximum possible image RMS contrast (when p=1) was approximately 0.022 (compared with the base image RMS contrast of approximately 0.072); in contrast, the maximum possible noise RMS contrast (when $p = 0$) was 0.22.

To extract orientation profiles, we carried out a classification image analysis (Eckstein & Ahumada, 2002; Gosselin & Schyns, 2004), analogous to a multiple linear regression of orientation bubbles on response accuracy. For each subject, a weighted sum of orientation sampling vectors was calculated, attributing positive/negative weights (standardized accuracies) to filters that led to correct/incorrect responses, respectively. The procedure generated n (sample size) vectors of regression coefficients (i.e., classification vectors) quantifying the association between orientations and face recognition accuracy. These were standardized using the mean and standard deviation of the null hypothesis, the parameters of which were estimated by simulating 1,000 classification vectors with as many random permutations of accuracies.

A group classification vector was then generated by summing individual vectors and dividing the outcome by $\sqrt{n}$. A pixel test (Chauvin, Worsley, Schyns, Arguin, & Gosselin, 2005) was applied to determine the statistical significance threshold ($Zcrit$ = 2.49, $p < .05$; two tailed). Figure 2 shows that, at the group level, information around the horizontal axis was positively correlated with face identification ($Zmax$ = 15.07), whereas oblique and vertical orientations were negatively correlated ($Zmin$ = −7.48), both $ps < 0.001$.

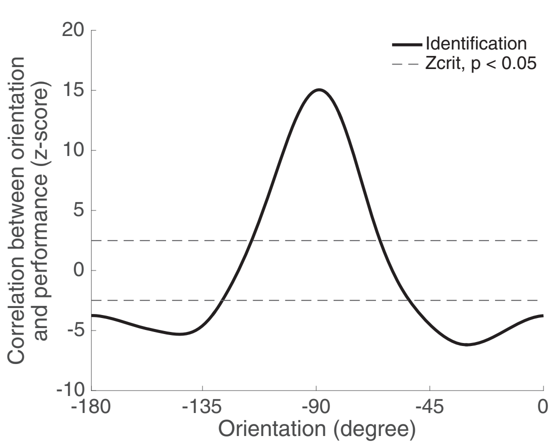

Figure 2. Group classification vector from the orientation bubbles task. Illustration of the correlation (z-score) between orientations and accuracy for face identification is shown. Gray dotted lines plot the two-tailed significance threshold.

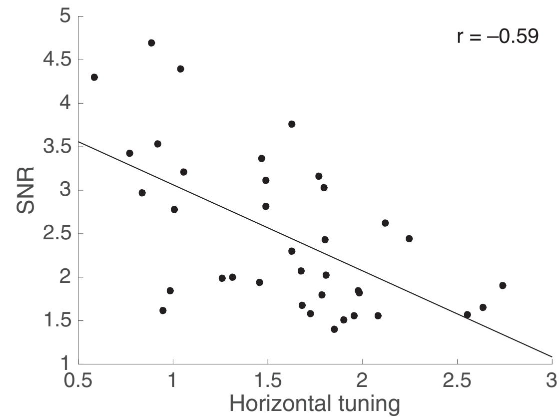

Figure 3. Scatterplot of the correlation between horizontal tuning and signal to noise ratio (SNR), $r = -0.59$, $p < .001$.

We then proceeded to verify the correlation between face identification ability and utilization of horizontal facial information. To generate the latter measure, we applied a 1D Von Mises distribution (sum equal to 1, full width at half maximum equal to 42° [the value best fitted to the data, and similar to Pachai, Bennett, & Sekuler, 2018]) on the −90° horizontal axis of standardized individual classification vectors. The sum of a resulting product vector then represents a weighted average of horizontal information utilization for a single subject and can be taken as an approximation of horizontal tuning—with maximum weight given to coefficients square on the horizontal axis, and a gradually decreasing weight given to coefficients as they fell farther away from this axis.

Horizontal tuning was negatively correlated with SNR thresholds (see Figure 3), $r_{\text{SNR, Tuning}} = -0.59$ ($r_{\text{Spearman}} = -0.59$), 95% CI [−0.75, −0.35], $p < .001$. Thus, participants who relied more selectively on horizontal facial information required less signal in the orientation bubbles task. This echoes the results of Pachai et al. (2013).

To verify the generalization of this relationship to other tasks, we first extracted a single measure of face-processing ability using the same procedure as in Royer, Blais, Gosselin, Duncan, and Fiset (2015, 2018), that is, submitting CFMT+, CFPT, and GFMT scores to a principal components analysis of the correlation matrix. The solution produced one component with eigenvalue >1. Factor loadings confirm that this component captures variance from each face processing task (CFMT+ = 0.84; CFPT = 0.7; GFMT = 0.47). Scores on this component correlated with SNR, $r_{\text{SNR, Ability}} = -0.65$ ($r_{\text{Spearman}} = -0.56$), $p < .001$, 95% CI [−0.79, −0.43], indicating that the bubbles task successfully captured individual differences in face-processing ability.

Critically, face processing ability correlated with horizontal tuning for faces (see Figure 4), $r_{\text{Ability, Tuning}} = 0.41$ ($r_{\text{Spearman}} = 0.37$), $p < .05$, 95% CI [0.11, 0.63]. Using Lee and Preacher's (2013; Steiger, 1980) web app for dependent correlations, we tested the difference between $r_{\text{Tuning, Ability}}$ and $r_{\text{Tuning, SNR}}$ and found it to be nonsignificant, $z = -1.51$, $p > .05$. Applying Fisher's transformation and a z test, we also compared $r_{\text{Tuning, Ability}}$ with the results of Pachai et al. ($r = .52$, $n = 32$) and found a nonsignificant difference, $z = -0.56$, $p > .05$.

Interestingly, $r_{\text{Tuning, Ability}}$ remained almost unchanged (z = 0.1, $p > .05$) after controlling for factors such as object recognition

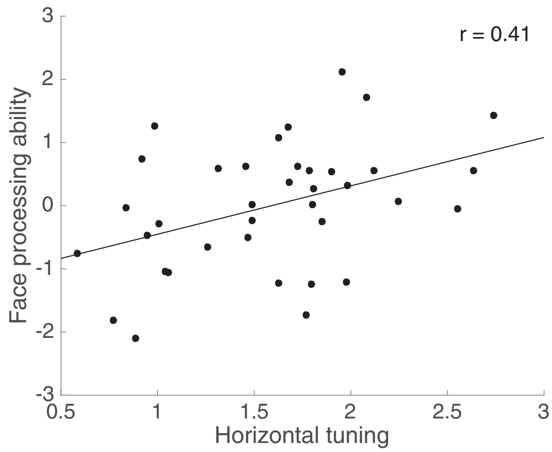

Figure 4. Scatterplot of the correlation between horizontal tuning and the face-processing ability score, $r = .41$, $p < .05$.

ability, horizontal tuning for cars (online supplemental Figure 1), and sensitivity to horizontal gratings (see, for details, online supplemental materials), $r_{\text{Partial}} = 0.39$, 95% CI [0.08, 0.64], $p < .05$. This is in line with previous results suggesting that the horizontal tuning observed in face recognition is task specific (Goffaux, 2019; Huynh et al., 2014) because the correlation between processing ability and horizontal tuning for faces is not predicated upon an overall better use of horizontal image structure. Thus, it may be that face recognition expertise begets selectivity to horizontal facial structure (see also Pachai et al., 2017), which would then be reflected in the more systematic deployment of the optimal (horizontally tuned) processing strategy (Royer et al., 2018).

Results similar to ours were obtained by correlating face-processing ability with utilization of the eyes (Royer et al., 2018), face selectivity of the fusiform gyrus (Furl, Garrido, Dolan, Driver, & Duchaine, 2011), and N170 latency (Herzmann, Kunina, Sommer, & Wilhelm, 2010). Interestingly, there is evidence to suggest that the fusiform face area and the N170 are both tuned to the eyes (Ghuman et al., 2014; Smith, Gosselin, & Schyns, 2004), to horizontal facial information (Goffaux et al., 2016; Hashemi, Pachai, Bennett, & Sekuler, 2018; Jacques, Schiltz, & Goffaux, 2014), and also that processing of horizontal facial structure is best predicted by utilization of the eyes (Duncan et al., 2017). Thus, it may be that reliance on horizontal facial information is the process binding these various associations with face processing ability.

Conclusion

Our results reinforce the case for the fundamental role of horizontal spatial orientations in face recognition by showing that the best face recognizers in three well-validated measures of individual differences in face-processing ability were more selectively tuned to this diagnostic information and that this association is likely task-specific.

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