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OBSERVATION

When Less Is More: Impact of Face Processing Ability on Recognition of Visually Degraded Faces

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It is generally thought that faces are perceived as indissociable wholes. As a result, many assume that hiding large portions of the face by the addition of noise or by masking limits or qualitatively alters natural "expert" face processing by forcing observers to use atypical processing mechanisms. We addressed this question by measuring face processing abilities with whole faces and with Bubbles (Gosselin & Schyns, 2001), an extreme masking method thought by some to bias the observers toward the use of atypical processing mechanisms by limiting the use of whole-face strategies. We obtained a strong and negative correlation between individual face processing ability and the number of bubbles ($r = -.79$), and this correlation remained strong even after controlling for general visual/cognitive processing ability ($r_{\text{partial}} = -.72$). In other words, the better someone is at processing faces, the fewer facial parts they need to accurately carry out this task. Thus, contrary to what many researchers assume, face processing mechanisms appear to be quite insensitive to the visual impoverishment of the face stimulus.

Keywords: bubbles, individual differences, face processing, holistic processing, psychophysics

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The idea that faces are recognized as a whole instead of as a collection of features is widespread in the literature (e.g., DeGutis, Wilmer, Mercado, & Cohan, 2013; Farah, Wilson, Drain, & Tanaka, 1998; Maurer, Grand, & Mondloch, 2002; Richler & Gauthier, 2014; but see Gold, Mundy & Tjan, 2012; Sekuler, Gaspar, Gold, & Bennett, 2004). A recurrent corollary of this hypothesis is that hiding large portions of the face by adding noise or by masking limits or qualitatively alters natural face processing (e.g., Macke & Wichmann, 2010; Orban de Xivry, Ramon, Lefèvre, & Rossion, 2008; Rossion & Boremance, 2008). However, this remains entirely speculative and has not yet been tested empirically.

One of the most extreme versions of the masking procedures, that is, the Bubbles technique (Gosselin & Schyns, 2001), has been cited many times as a way to force atypical face processing strategies such as feature-based processing (e.g., Neath & Itier, 2014; Pellicano, 2008; Rossion, 2009, 2014) or attention to local cues (e.g., Goffaux & Rossion, 2006; Murray & Gold, 2004; Piepers & Robbins, 2012; Song, Kawabe, Hakoda, & Du, 2012; Thurman, Giese, & Grossman, 2010; Vuilleumier, 2005). Bublized stimuli are presented through a restricted number of small apertures. It is important to note that to ensure the presence of identification errors, the number of apertures is adjusted: The better a participant is with bubblized stimuli, the less visual information is made available to them. Considerable individual differences exist in the number of bubbles required to complete a given task (e.g., Adolphs et al., 2005; Butler, Blais, Gosselin, Bub, &

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Fiset, 2010; Caldara et al., 2005), as well as in face-specific abilities (e.g., DeGutis et al., 2013; Richler, Cheung, & Gauthier, 2011; Wang, Li, Fang, Tian, & Liu, 2012). If visually altering the stimulation does bias observers toward the use of atypical face processing mechanisms, there is no a priori reason to believe that the ability with these atypical/unpracticed strategies will be highly correlated with the typical ones used with whole-face stimuli, especially if general visual/cognitive mechanisms are removed from the equation. In the present study, we correlated the number of bubbles a participant needs to accurately recognize a face with the performance in three tasks in which the whole face stimulus is available. Because many consider face processing as the by-product of both general visual/cognitive abilities and face-specific abilities, we factored out the former with a partial correlation analysis (see Wang et al., 2012, for a similar logic). This analysis allows us to conclude that a large amount of variance in face-specific abilities is captured even when the facial stimuli are visually degraded. These results offer interesting insight about how face recognizers of varying ability differ in the way they process faces.

General Method

Participants

Thirty-five Caucasian, right-handed participants (between the ages of 18 and 34; $M = 23.63$, $SD = 4.05$) completed seven tests for this study: three face recognition tasks, three object recognition tasks, and an ABX, match-to-sample Bubbles task. The number of participants was set at 35 in order to include a wide range of individual differences in face and object recognition ability in our sample (see Furl, Garrido, Dolan, Driver, & Duchaine, 2011 and Richler et al., 2011, for similar sample sizes). All participants had normal or corrected-to-normal visual acuity.

Apparatus

The experiments were conducted on MacPro QuadCore computers. Stimuli were displayed on a 22-inch 120-Hz Samsung LCD monitor. The monitor's resolution was set to 1680×1050 pixels. Minimum and maximum luminance values were 0.4 cd/m^2 and 101.7 cd/m^2, respectively. The participants were seated in a dark room and viewing distance was maintained constant at 57 cm using a chinrest.

Face and Object Tasks

Each participant completed a total of six tests using whole stimuli: the Cambridge Face Memory Test + (CFMT+; noise is added only in the most difficult condition), the Cambridge Face Perception Test (CFPT), the Glasgow Face Matching Test short version (GFMT), the Horse Memory Test (HMT), the Cambridge Car Memory Test (CCMT), and the Cambridge Hair Memory Test (CHMT). Further details, references, and descriptive statistics regarding each task can be found in the online supplemental material. All Cambridge tests were programmed in Java; the others (GFMT and HMT) as well as the Bubbles experiment were programmed in Matlab (Natick, MA) using functions from the Psychophysics toolbox (Brainard, 1997; Pelli, 1997). We also computed a global face score and a global object score by calculating, for each participant, their average score across the three face-related tasks and the three object-related tasks (the raw scores for each individual task were converted to *z* scores beforehand).

Bubbles Task

The stimuli presented during this task consisted of 30 identities from the *Fundação Educacional Inaciana* (FEI) Face Database (15 females; Thomaz & Giraldi, 2010). All chosen identities exhibited a neutral facial expression. The grayscale stimuli were revealed through an elliptical aperture, which masked their external facial features. Image resolution was 256×256 pixels, and the face width was 6 degrees of visual angle (Yang, Shafai, & Oruc, 2014). The spatial frequency spectrum was equalized using SHINE (Willenbockel et al., 2010), and the stimuli from each condition (see below) were spatially aligned on the positions of the main internal facial features (eyes, mouth, and nose) using translation, rotation, and scaling.

To create a *bubblized* stimulus, a face (Figure 1A) was first decomposed into five different spatial frequency (SF) bands (Figure 1B; 106.2–53.1, 53.1–26.6, 26.6–13.3, 13.3–6.6, and 6.6–3.3 cycles per face, the remaining low-frequency band serving as a constant background) using the Laplacian pyramid transform implemented in the pyramid toolbox for Matlab (Simoncelli, 1999). Each SF band was then independently and randomly sampled with Gaussian apertures (i.e., bubbles) of different standard deviations. More specifically, the size of the bubbles was adjusted in accordance with frequency band to only reveal three cycles (Figure 1C). Because the size of the bubbles is much larger for lower SF bands, the number of bubbles was adjusted at each scale to maintain the probability of a given pixel being revealed constant across SF bandwidths. A point-wise multiplication was then performed between the bubbles' masks and the filtered images to obtain one bubblized face for each SF band (Figure 1D). Finally, these five randomly sampled images plus the constant background were summed to produce the bubblized stimulus, that is, what is shown to the participant on a given trial (Figure 1E).

A 500-ms fixation point initiated each trial. Then, one of the 30 possible identities (i.e., the study face) was presented for the same duration (i.e., 500 ms). The study face's pose was randomly chosen to either be a full frontal view or a 3/4 view facing either toward the left or the right. A 100-ms white noise mask immediately followed the study face. Finally, two bubblized frontal view faces (i.e., the test faces) were presented side-by-side and kept on screen until the subject indicated which of the two stimuli was the same identity as the study face; one of the test faces was the previously viewed face and the other, one of the randomly chosen 14 other possible faces of the same gender (see the online supplemental material for stimulus examples and for an illustrated outline of a given trial). Each participant completed 15 blocks of 120 trials each, for a total of 1,800 trials. The number of bubbles was adjusted independently for each pose condition using QUEST (Watson & Pelli, 1983) to maintain an accuracy rate of 75%. A single adjustment procedure was used for all spatial scales; the amount of information revealed at each scale was manipulated in such a way that, in average, an equal amount of information (i.e., the same number of pixels) was revealed across SF bandwidths. Our

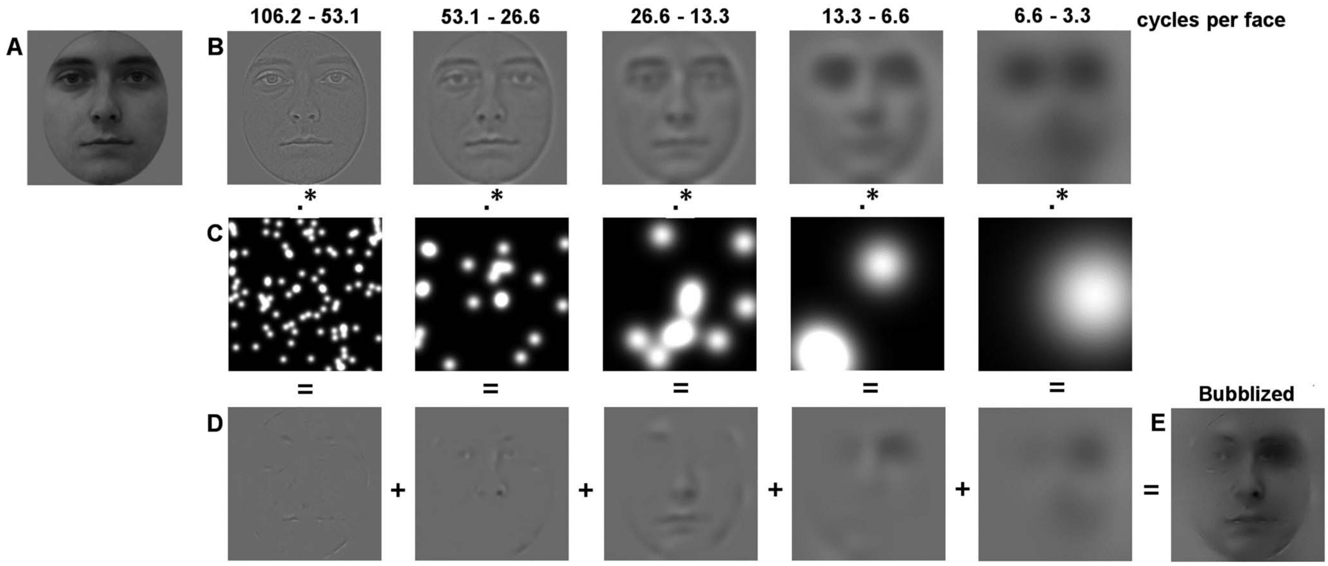

Figure 1. Creation of the bubblized stimulus using an exemplar from the FEI Face Database (Thomaz & Giraldi, 2010). The original stimulus (A) is filtered into the five spatial frequency bands in B. In each band, a number of randomly positioned Gaussian apertures puncture a homogeneous black field (C). Applying the punctured masks to the filtered stimulus reveals the information in each band (D). This spatially filtered information is then summed, producing a bubblized stimulus (E).

index of performance was the number of bubbles that the participant required to maintain accuracy at 75%: the lower this index, the better the performance.

Results and Discussion

A repeated-measures analysis of variance determined that the number of bubbles significantly differed across pose conditions, $F(2, 34) = 78.48$, $p < .0001$. Bonferroni-corrected paired-sample t tests revealed that the easiest condition was the full frontal view, $M = 79.79$, 95% confidence interval (CI) [69.72, 89.85]; $SD = 29.29$, followed by the right 3/4 view ($M = 111.08$, 95% CI [97.67, 124.50]; $SD = 39.04$), $t(34)_{\text{front-right}} = -10.09$, $p < .0001$, $d = -.91$, and the left 3/4 view ($M = 126.75$, 95% CI [110.20, 143.30]; $SD = 48.18$), $t(34)_{\text{right-left}} = -4.75$, $p = .0001$; $d = -.36$. A left-eye bias has been observed in many studies investigating perceptual face recognition strategies (e.g., Vinette, Gosselin, & Schyns, 2004); it is thus possible that the 3/4 left condition was the most difficult simply because this pose partially occludes the left side of the face.

Next, we measured the strength of the association between the global face score and the performance in the last completed block of our Bubbles task. The correlations were strong when averaging across viewpoint conditions ($r_{\text{all}} = -.79$, $p < .0001$; Figure 2) as well as in each individual condition ($r_{\text{front}} = -.77$; $r_{\text{right}} = -.80$; $r_{\text{left}} = -.72$; all ps $< .0001$).

Seeing as the correlation between two measures is limited by their reliability, we computed Cronbach's alpha for our face recognition tests in order to determine the upper bound correlation between these measures and our bubbles task. Based on our data, the combined alpha for the CFMT, CFPT and GFMT is .87. However, it is not as straightforward to compute Cronbach's alpha for the bubbles task, because the number of bubbles on a given trial is the result of a continuous optimization process, and cannot be expressed as the sum of a set of subcomponents. We thus estimated the reliability of the bubbles task by correlating the number of bubbles at the last trial of the 7th block with the number of bubbles at the last trial of the last block ($r = .95$, $p < .0001$). We performed the correlation on such distant trials to ensure that the number of bubbles had been adjusted on a reasonable amount of trials in order for individual differences to emerge. Considering that the upper-bound correlation between two tests is defined as

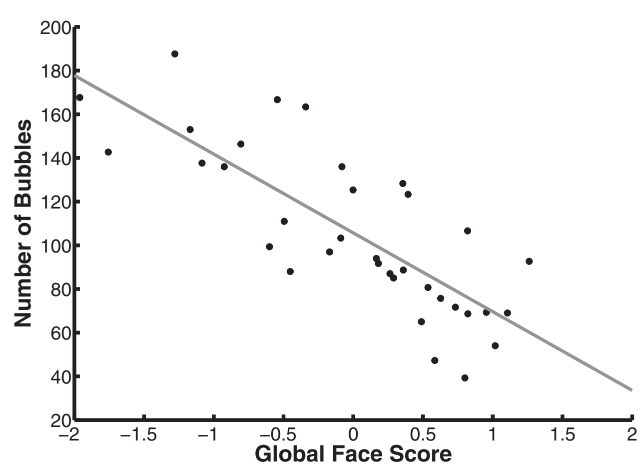

Figure 2. Correlation between individual face recognition ability as measured with the global face score (see General Method) and the mean number of bubbles in the last completed block of our Bubbles task ($r = -0.79$, $p < .0001$).

the square root of the product of the reliabilities of both measures (Nunnally, 1970), the maximum correlation we could have obtained with our data is −.91. Thus, the amount of information required by each participant to accurately recognize faces explains 62% of the variance (out of a possible 83%) in individual face processing ability.

Most important, the correlations between the global face score and performance in our Bubbles task remained strong, though modestly lower, even when factoring out the global object score ($r_{\text{partial,all}} = -.72$, $p < .0001$). Even considering an individual's more general visual abilities, which are common to both face and object recognition, individual performance with Bubbles is still highly correlated with face processing ability. It is interesting to note that the partial correlation remains strong for each condition in the Bubbles task ($r_{\text{partial,front}} = -.71$; $r_{\text{partial,left}} = -.66$; $r_{\text{partial,right}} = -.74$; all $ps < .0001$), meaning that our participants' ability to use a purely image-based recognition strategy cannot explain the present results.

We also submitted the data obtained on the six face and object recognition tests to a principal components analysis (PCA) of the correlation matrix with varimax rotation of the resulting eigenvector components. We retained the first two factors in our analyses (eigenvalues >1) and computed our participants' factor scores on these two factors. The three face recognition tests mostly loaded on the first factor (.74 for the CFMT+, .85 for the CFPT, and .69 for the GFMT), and the object recognition tests mostly loaded on the second (.67 for the HMT and .73 for the CCMT; however, the CHMT mostly loads on the first factor at .74). In line with our previous correlational analyses, we obtained a very high correlation between the average number of bubbles across all conditions and the individual scores on the first factor ($r_{\text{all}} = -.78$, $p <$ .0001), but not on the second factor ($r_{\text{all}} = -.19$, *ns*).

Conclusion

Many researchers assume that upright faces are processed as a indissociable whole; it is this particular type of processing mechanism that would make faces a "special" stimulus category, as it would mean they are processed in a qualitatively distinct manner than other object categories. It is also assumed that natural 'expert' face-specific processing requires access to the whole face stimulus. This implies that methods hiding large portions of the face, such as Bubbles, may disrupt natural face processing by biasing the observer toward an atypical recognition strategy. If this is the case, then we should not expect the best face-recognizers to better use this unnatural strategy; we directly tested this question using an individual differences approach. We measured the strength of the association between whole face recognition abilities and the performance during a Bubbles match-to-sample task and show a strong correlation between these two measures. It is important to note that even when general visual/cognitive abilities are factored out, the correlation remains strong and significant. In short, our main conclusion is the following: Individual differences in face processing ability do not require the whole face stimulus.

Our results bring an interesting perspective on the mechanisms by which the best recognizers process faces; indeed, these individuals need less visual information to identify a face at a given level of accuracy. It is possible that the best face-recognizers possess the most detailed visual representation of the faces they encounter, and even a very small amount of information is sufficient for the reactivation of these representations. On the other hand, the least skillful observers require considerably more information in order to activate their facial representations, and may even practically need the whole face stimulus to appropriately complete this task (see Figure S2 in the supplemental materials available online). This may explain why superrecognizers (Russell, Duchaine, & Nakayama, 2009) are able to recognize people that they have not seen for an extent period of time. Because their facial representations are extremely clear, any correlation with a portion of the face stimulus would be sufficient to activate its representation, even years later. In this sense, the best face recognizers would be less affected by noisy identification conditions possibly due to the precision and flexibility of their representations of faces. This flexibility could generalize to variations in stimulus pose, lighting, facial expression, and so forth as seen, for instance, in the most difficult condition of the CFMT+.

We have shown that more than 50% of the observed variance in face-specific processing abilities is captured by a very simple measure: the number of bubbles (i.e., quantity of information) required to maintain a given level of performance. Thus, if it is holistic processing that determines the differences in face recognition performance (DeGutis et al., 2013; Richler et al., 2011; Wang et al., 2012; but see Konar, Bennett, & Sekuler, 2010), this mechanism must be thought as quite insensitive to the visual impoverishment of the face stimulus and as coming into play at the representational level (see Rossion & Boremance, 2008 for a similar proposal).

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