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BRIEF REPORT

The perception of a face can be greater than the sum of its parts

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Abstract Holistic processing is often used as a construct to characterize face recognition. An important recent study by Gold, Mundy, and Tjan (2012) quantified holistic processing by computing a facial-feature integration index derived from an ideal observer model. This index was mathematically defined as the ratio of the psychophysical contrast sensitivities squared for recognizing a whole face versus the sum of contrast sensitivities squared for individual face parts (left eye, right eye, nose, and mouth). They observed that this index was not significantly different from 1, leading to the provocative conclusion that the perception of a face is no more than the sum of its parts. What may not be obvious to all readers of this work is that these conclusions were based on a collection of faces that shared essentially the same configuration of face parts. We tested whether the facial-feature integration index would also equal 1 when faces have a range of configurations mirroring the range of variability in real-world faces, using the same experimental procedure and calculating the same integration index as Gold et al. When tested on faces with the same configuration, we also observed an integration index similar to what Gold et al. reported. But when tested on faces with variable configurations, we observed an integration index significantly greater than 1. Combing our results with those of Gold et al. further clarifies the theoretical construct of holistic processing in face recognition and what it means for the whole to be greater than the sum of its parts.

Keywords Holistic processing · Configuration · Face recognition

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Holistic processing is commonly used to characterize some of the important differences between expert face perception and general object perception (e.g., see Maurer, Le Grand, & Mondloch, 2002; Richler, Palmeri, & Gauthier, 2012). Researchers have used various tasks to index holistic processing of faces, including the composite task (Young, Hellawell, & Hay, 1987), the part-whole task (Tanaka & Farah, 1993), and the inversion task (Yin, 1969), among others (see Richler et al., 2012). These tasks reveal costs and benefits to face recognition performance depending on factors like orientation, configuration, and context. While views differ regarding how to properly measure holistic processing (Richler & Gauthier, 2013; Rossion, 2013) and how to best characterize holistic processing theoretically (Fific & Townsend, 2010; Mack, Richler, Gauthier, & Palmeri, 2011; Richler, Gauthier, Wenger, & Palmeri, 2008; Silbert & Thomas, 2013; Wegner & Ingvalson, 2002), most would agree that face recognition is holistic in some respect, whatever that respect might be. This makes the recent finding by Gold, Mundy, and Tjan (2012) that "the perception of a face is *no more* than the sum of its parts" (emphasis added) all the more provocative and important.

Beginning with the premise that "most current theories of face perception assert that the ability to recognize a human face is not simply the result of an independent analysis of individual features, but instead involves a holistic coding of the relationships among features", Gold et al. compared observed human face recognition performance to that predicted by an optimal Bayesian integrator that combines information from individual face parts without considering the configurations of those face parts. Human performance that is better than predicted by this ideal observer model would provide a marker of holistic processing – something is gained when face parts appear in the orientation, configuration, and context of a real face compared to when those same face parts appear in isolation.

Specifically, Gold et al. (2012) defined an integration index derived from a particular optimal Bayesian integrator (see Nandy & Tjan, 2008, for details). This index (Φ) was defined as

$$\phi = \frac{S^2_{\text{combined}}}{S^2_{\text{left eye}} + S^2_{\text{right eye}} + S^2_{\text{nose}} + S^2_{\text{mouth}}} \quad (1)$$

where S is the reciprocal of a subject's psychometric contrast threshold for identifying an intact whole face (S_{combined}) or identifying its individual face parts presented in isolation ($S_{\text{left eye}}$, $S_{\text{right eye}}$, S_{nose}, and S_{mouth}). Both conceptually and mathematically, this index measures whether the whole face is greater than, equal to, or less than the sum of its face parts.

For upright faces, they observed that the integration index was not significantly different from 1. Based on their ideal observer model, the whole face is no greater than the sum of its parts. Faces are not processed holistically.

The face stimuli used in Gold et al. are reproduced in Fig. 1. The intact faces used in their first experiment, which we adapted for our experiments, consisted of Gaussian windows placed over the locations of the eyes, nose, and mouth against a grey background (in another experiment, when these face parts were instead placed on an average face background, similar findings were observed by Gold et al.).

What may not be obvious from reading Gold et al. or from visually inspecting Fig. 1 is that the six faces all shared a very similar configuration. For example, five of the six faces measured essentially the same distance between the centers of the two eyes and the sixth was only slightly different from the others. Using arbitrary measurement units[1] for the Gold et al. faces, we calculated that the eye to eye distance ranged from 65 to 69, the eyes to nose distance ranged from 39 to 46, and the nose to mouth distance ranged from 29 to 33. For comparison, for similarly-sized real face images from the MPI database of 200 faces, using the same arbitrary measurement units, we calculated that the eye to eye distance ranged from 55 to 74, the eyes to nose distance ranged from 30 to 48, and the nose to mouth distance ranged from 22 to 39.

The face stimuli used in Gold et al. (2012) were simply described as being "three male and three female faces used in previous experiments on face recognition (Gold, Bennett, & Sekuler, 1999a, 1999b)" (p. 428). There was no discussion in that earlier work or in Gold et al. of explicitly equating faces based on their configuration, and any explicit intent to do so would certainly have impacted their theoretical discussion, especially given their explicit rejection of a notion that "face recognition involves a holistic encoding of the relationships among features" (p. 427).

In fairness, having faces roughly equated for configuration was likely a consequence of having to satisfy requirements of the ideal observer model on which the integration index is derived, namely ensuring that face features were orthogonal to one another, with no spatial overlap (Nandy & Tjan, 2008; Gold et al., 2012). Meeting this requirement given the face database used in their earlier work, they were left with faces having the same configuration of face parts. Here we added variability in configuration, maintaining the requirement of orthogonality.

Our goal was simply to test whether the integration index would be significantly greater than 1 if the six faces had a range of configurations similar to the range of configurations observed in real world faces. Experiment 1 was a replication of the first experiment of Gold et al. Experiment 2 was an extension using faces with different configurations of face parts. Since the two experiments differ only slightly in their methods and are analyzed in the same way, we report them jointly.

Methods

Participants For both experiments, we targeted ten individuals for recruitment (Experiment 1 included seven women, their age ranged 18–26 years; Experiment 2 included two women, their age ranged 18–26 years.). Participants received course credit or $12 per hour for their participation. All reported normal or corrected-to-normal vision. All participants gave written, informed consent in accordance with the procedures and protocols approved by the Institutional Review Board at Vanderbilt University.

Stimuli In our Experiment 1, we used the same face stimuli as in Experiment 1 of Gold et al. (2012). Exactly following the stimulus creation procedures they used, for each of the six original gray-scale faces (three female and three male), stimuli for five conditions were created: the left eye, the right eye, the nose, the mouth, and the combined condition. To produce stimuli for the four part conditions (see first four rows of Fig. 1), the individual facial features were isolated from each face by applying separately four small Gaussian windows centered on each of the four parts; for example, by applying the Gaussian window to the left eye region of a face, a stimulus for the left eye condition was isolated. To produce stimuli for the combined condition (see fifth row of Fig. 1), all

[1] Face images were presented on a computer screen in a custom Matlab program that collected mouse clicks from a researcher recording the center of each eye, the tip of the nose, and the center of the mouse. Distances between parts were calculated from these recordings. The units are "arbitrary" only in the sense that the face images were presented at a size that permitted quick, easy, and accurate location of these fiducial markers by the researcher. The units are not scaled to the actual size of the original face nor to the size of the faces used in the experiments. The purpose here was simply to compare the range of measures for the Gold et al. faces relative to those from a larger dataset of real faces.

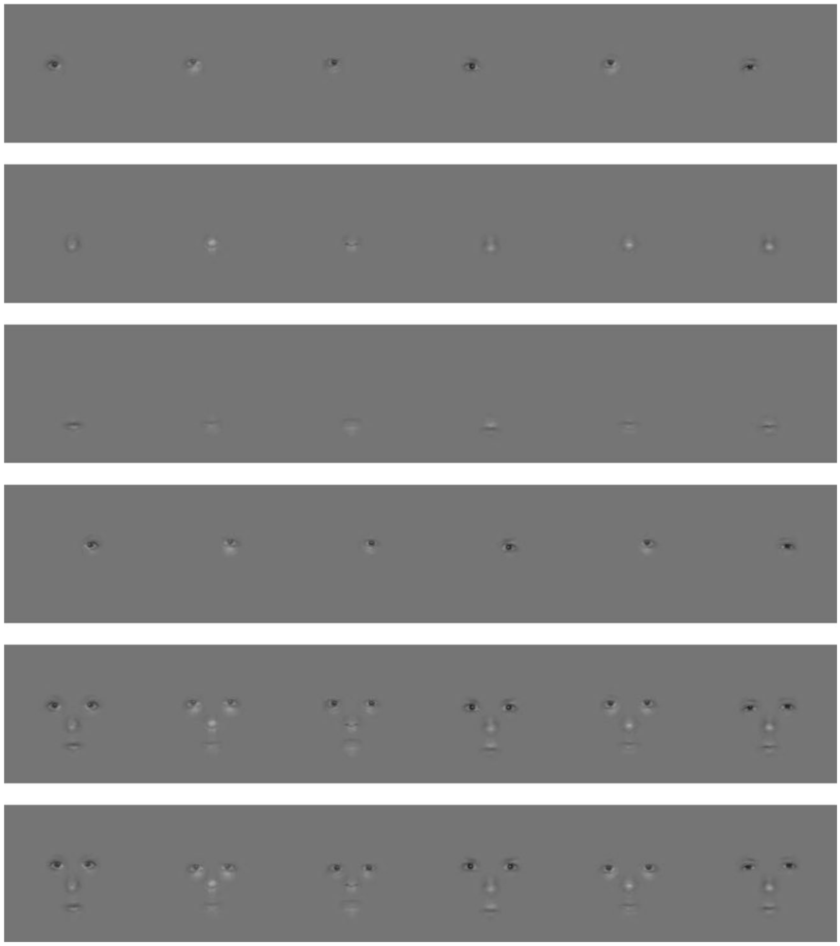

Fig. 1 Stimuli used in Experiments 1 and 2. In Experiment 1, we replicated the design of Gold et al. (2012). There were five conditions, one combined condition with faces having essentially the same configuration of face parts (fifth row) and four isolated part conditions (top four rows). In Experiment 2, we varied naturally the configurations of the six face parts. There were again five conditions, one combined condition with varied face part configurations (sixth row) and four isolated part conditions (similar to top four rows, but face parts appeared in varied locations as in the combined condition). Figure adapted from Gold et al. (2012)

four windows were applied simultaneously to generate a combined set of features (the two eyes, nose, and mouth) for each face. The face parts, whether individually or in combination, were shown against a neutral gray background, as in Experiment 1 of Gold et al.; as noted earlier, when Gold et al. presented the face parts embedded within an average face instead of a gray background, the same qualitative results were observed.

For Experiment 2, we modified the face stimuli in one key way – adding natural configural variability, but used the same procedure to create the stimuli for both the isolated and the combined conditions. First, starting with the faces used in our Experiment 1 and in Gold et al., we added variability in configuration by moving the two eyes closer together or further apart, moving the two eyes up or down, and moving the mouth up or down. To make the faces appear natural, we ensured that the new configurations lay within the range of configurations we measured in the faces in the MPI Face Database (Troje & Bülthoff, 1996). We also ensured that there was no spatial overlap between features in any of the faces, to satisfy the requirement of the ideal observer model and the integration index; meeting this orthogonality requirement meant that most variability was in the eye separation and eye height.[2] Second, after generating the face stimuli, we created the stimuli for the isolated and the combined conditions in the same way as in Experiment 1, applying four small Gaussian windows centered on each of the four parts either separately or simultaneously. Therefore, the stimuli used in both the isolated and the combined conditions (see bottom row of Fig. 1)

[2] In an initial version of this manuscript, being unaware of the orthogonality requirement of the ideal observer model, we had more variability in the mouth position as well, but that resulted in some overlap of face features. The integration index observed in that experiment was numerically quite similar and statistically no different from the integration index we report here.

differed only in one respect from those used in Experiment 1 – the features appeared in varied locations.

Design and procedure The procedure followed exactly the same experimental procedures used by Gold et al. In fact, our experiment was based on the same Matlab programs used by Gold et al. (see Acknowledgements). All that we changed was the configural information in the faces we used in Experiment 2, as described above.

Each trial required the participant to either identify a face part presented in isolation or the entire face. The part trials and whole face trials were randomly intermixed. The contrast of the test image was adjusted using a staircase procedure, with separate staircases for each part and whole face conditions. To comply with the requirements of the integration index (Gold et al., 2012), contrast was defined as 'nominal contrast': the contrast that the combined image was set to before the features were removed when presenting an isolated feature.

On each trial, participants first saw a blank screen. After they clicked the mouse to initiate the trial, a part or a whole face (depending on the condition) would be presented against a gray background for 500 ms. Subsequently, a selection screen with all six possible parts or six possible whole combined faces (depending on condition) was displayed in a 2×3 array. Subjects made their identification response (which nose, which eye, which mouth, which whole face did they just see) by clicking on one of the six possible parts or whole faces presented on the screen. For example, on a given trial in the nose condition, first the participant would see one particular nose for 500 ms, then see a selection window containing all six possible noses, and then identify the nose they had seen by clicking on its image. Feedback was provided after each response; a high-pitched tone denoted a correct response and a low-pitched tone denoted an incorrect response.

Following Gold et al., contrast of the images was adjusted from trial to trial using an adaptive staircase procedure. There was a separate staircase for each condition, four staircases for each individual face part and one staircase for the combined face. The key measurements were the 50 % contrast thresholds (17 % was chance) in each condition obtained by fitting psychometric functions to the contrast-staircased identifications. These contrast thresholds were used to calculate the integration index per Equation 1.

Participants sat in a dark room about 135 cm away from the monitor (19" Mitsubishi Diamond Pro 920 CRT). Each session took approximately 1 hour. Each participant completed five sessions over five days. All five sessions were identical except for the randomized stimulus presentation order; following Gold et al., the first two sessions were discarded due to learning effects. In each session, there were 120 trials for each condition, consisting a total of 600 trials.

Results

We first calculated participants' 50 % contrast thresholds. Psychometric functions were fitted to data from the last three sessions using the psignifit toolbox (Fründ, Haenel, & Wichmann, 2011). After fitting the function, using tools in psignifit, we found the 50 % contrast threshold for each condition for each participant in each experiment (see Table 1). Like Gold et al., we then calculated sensitivities as the reciprocal of the contrast thresholds (Nandy & Tjan, 2008). The facial-feature integration index was then computed for each subject in Experiments 1 and 2 using Equation 1. Like Gold et al., we conducted a t-test to compare the log index with 0 (which of course corresponds to an index of 1). Standard deviations, SEMs, and confidence intervals on all threshold and index estimates were obtained via bootstrap simulations (Wichmann & Hill, 2001); to match how data was summarized in Gold et al., we show standard deviations for individual subject data in Table 1 and SEMs for group averages in Fig. 2.

The mean integration indices for Experiments 1 and 2 are plotted in Fig. 2. In Experiment 1, when all the faces shared exactly the same configuration, we observed a mean integration index of 0.77 ($SD = 0.16$). The log index was significantly smaller than 0 ($t(9) = -4.53$, $p < 0.05$), the 95 % confidence interval of the log index was [−0.18, −0.06], and the calculated effect size was 1.43 (Cumming, 2012). Following Gold et al., analyses were performed on log indices because of statistical properties of contrast thresholds. A Welch Two-Sample t-test showed that there was no statistical difference between the indices in our Experiment 1 and the indices reported by Gold et al. (2012) ($t(4.71) = 0.004$, $p = 1.00$), the 95 % confidence interval of the difference between the log indices was [−0.25, 0.25], and the calculated effect size was 0.002. We had twice the number of participants in our experiment, which may partially explain why we found our indices significantly less than 1 when Gold et al. did not, even though the indices were numerically similar.

In Experiment 2, when faces varied in configuration, we observed a mean integration index of 1.58 ($SD = 0.62$). The log index was significantly greater than 0 ($t(9) = 2.96$, $p < 0.05$), the 95 % confidence interval of the log index was [0.04, 0.29], and the effect size was 0.94.

We also performed a post-hoc comparison of the results of Experiments 1 and Experiment 2. A Welch Two-Sample t-test showed that the integration index for faces with varied configurations (Experiment 2) was significantly larger than that for faces with the same configuration (Experiment 1) ($t(12.96) = 4.63$, $p < 0.05$). The 95 % confidence interval of the difference between the log indices was [0.15, 0.42], and the effect size was 2.07.

Table 1 Individual Participants' Average Sensitivity^2 (1/Threshold^2) for Each Face Part (Left Eye, Right Eye, Nose, Mouth) and Combined Face (Combined), and Integration Index in Experiments 1 and 2; Standard Deviations of Each Measure (in Parentheses) were Obtained by Parametric Bootstrap Simulation

	Left Eye 1.0e4 (1.0e3)	Right Eye 1.0e4 (1.0e3)	Nose 1.0e4 (1.0e3)	Mouth 1.0e4 (1.0e3)	Combined 1.0e4 (1.0e3)	Integration Index
Experiment 1						
CW	5.74 (4.25)	6.54 (5.26)	1.22 (1.04)	0.53 (0.95)	8.68 (5.99)	0.62 (0.06)
EW	1.51 (1.45)	2.61 (2.57)	0.50 (0.43)	0.43 (0.35)	4.44 (4.35)	0.88 (0.11)
AM	1.22 (1.39)	1.23 (4.05)	0.06 (0.06)	0.09 (0.03)	1.91 (4.72)	0.73 (0.14)
YZ	4.70 (5.17)	3.21 (3.09)	0.92 (0.90)	0.36 (0.27)	8.09 (5.16)	0.88 (0.11)
SS	5.50 (3.90)	5.37 (4.41)	1.19 (1.73)	0.91 (0.82)	8.71 (7.19)	0.67 (0.07)
XJ	2.39 (2.99)	2.48 (1.87)	1.03 (1.25)	0.55 (0.50)	7.22 (6.00)	1.12 (0.11)
WL	0.13 (0.11)	0.17 (0.20)	0.75 (2.32)	0.41 (0.94)	1.12 (2.83)	0.76 (0.18)
WL	0.93 (2.13)	0.73 (0.43)	0.77 (1.42)	0.09 (0.06)	1.83 (1.96)	0.73 (0.07)
YG	1.21 (3.40)	2.10 (1.59)	1.18 (0.72)	0.20 (0.14)	3.40 (3.13)	0.73 (0.08)
JF	4.78 (6.99)	4.82 (3.17)	1.58 (0.93)	0.52 (0.37)	6.53 (6.13)	0.56 (0.07)
Experiment 2						
MS	0.16 (0.14)	0.15 (0.16)	0.12 (0.15)	0.07 (0.29)	0.92 (1.09)	1.82 (0.27)
JS	4.97 (5.45)	4.62 (5.07)	2.11 (1.44)	0.46 (1.15)	10.8 (8.17)	0.88 (0.07)
HJ	2.64 (2.65)	1.98 (3.45)	0.23 (0.21)	0.20 (0.14)	8.73 (10.2)	1.73 (0.23)
LP	0.25 (0.21)	0.26 (0.23)	0.07 (0.10)	0.11 (0.16)	0.66 (0.40)	0.95 (0.08)
ST	1.25 (1.12)	1.18 (0.87)	0.49 (1.47)	0.13 (0.11)	7.83 (5.35)	2.57 (0.18)
NA	0.44 (0.50)	0.50 (13.2)	0.35 (2.10)	0.18 (0.14)	3.52 (3.57)	2.37 (0.41)
KE	1.47 (2.79)	3.81 (2.82)	0.64 (1.78)	0.33 (0.22)	6.44 (5.69)	1.03 (0.12)
BW	0.76 (0.83)	0.71 (0.51)	0.11 (0.05)	0.11 (0.07)	2.67 (2.76)	1.58 (0.23)
MH	0.13 (0.10)	0.10 (0.09)	0.06 (0.10)	0.06 (0.06)	0.68 (0.40)	1.93 (0.13)
RT	0.67 (1.82)	2.40 (2.01)	0.37 (0.19)	0.26 (0.29)	3.33 (4.12)	0.90 (0.07)

Discussion

It has long been claimed that people recognize faces holistically – a face is greater than the sum of its parts. The eyes, nose, mouth, and other face features are recognized simultaneously and the relationships among those features provide critical information for telling one face from another face. Few have disagreed that face recognition is holistic. Rather, debate has centered around what it means for face recognition to be holistic (e.g., Fific & Townsend, 2010; Mack et al., 2011; Richler et al., 2008; Silbert & Thomas, 2013; Wegner & Ingvalson, 2002). The surprising results from Gold et al. suggest instead that "the perception of a face is no more than the sum of its parts" (see also Gold et al., 2014).

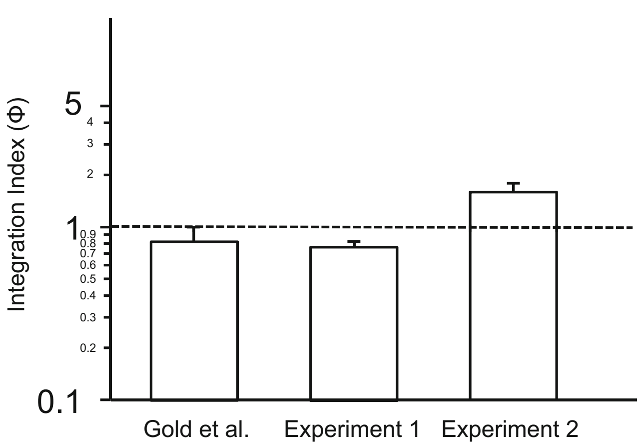

Fig. 2 Mean integration index for Gold et al. (2012), Experiment 1, and Experiment 2, left to right, respectively; error bars are +1 SEM. The optimal index is 1, which is highlighted by the dashed horizontal line

To test for holistic processing, Gold et al. began with a non-holistic, optimal Bayesian integrator – an ideal observer model – that assumes that performance on the whole can be predicted by performance on the individual parts. A signature of holistic processing would be superoptimal integration greater than that predicted by the non-holistic ideal observer. Gold et al. reported an integration index not significantly different from 1, the value predicted by the non-holistic ideal observer. Using the same faces as Gold et al. in our Experiment 1, we observed an integration index that was numerically similar to what they reported, although with our additional statistical power, we actually observed an index that was statistically less than 1 (we note that the second experiment of Gold et al. similarly reported an integration index marginally less than 1). Integration is not superoptimal, it is not holistic.

Faces differ in their features – different shapes of eyes, noses, and mouths – but they also differ in their configuration (e.g., Rhodes, Brake, Taylor, & Tan, 1989). We were surprised to discover upon closer examination that the faces used in Gold et al. had virtually the same configuration of face parts. While controlling explicitly for configuration is certainly common in the face recognition literature (e.g., Amishav & Kimchi, 2010; Richler, Palmeri, & Gauthier, 2013, 2014), neither Gold et al. nor papers that preceded it (Gold et al., 1999a) noted any explicit aim to control for configuration of face parts. When we instead used faces with a natural range of variability in configuration in our Experiment 2, we observed an integration index that was significantly greater than 1, superoptimal, holistic.

Making sense of this difference can start with considering how we interpret the integration index. Assume there are separate visual channels that process each eye, the nose, and the mouth. Putting aside the question of whether there are also channels that process the configuration of those face parts, we can ask whether or not the channels dedicated to individual faces parts are more efficient when other face parts are present in the image compared to when they are shown in isolation. Is there cross-talk or are the channels independent of one another? If there is cross-talk, and that cross-talk is beneficial to recognition, this would be a sense in which the whole is greater than the sum of its parts (Fific & Townsend, 2010). When configuration is non-diagnostic, in other words, when configuration is held constant, there is something special perceptually about having all of the face parts shown simultaneously. This seems close to the sense of holistic processing tested by the ideal observer model in Gold et al.

However,these abovementioned caveats about holding configuration constant, making configuration non-diagnostic, are critical. Gold et al. used faces with little configuration, effectively holding configuration constant. They found that the integration index was not significantly different from 1, and concluded that faces are processed non-holistically, neglecting the contribution of configural information to face recognition. We replicated their results, observing indices that were statistically equivalent to their indices. These findings together suggest that there may be relatively little cross-talk between channels that process face features, but this does not mean that the configuration of those features plays no role in face recognition (see Richler, Palmeri, & Gauthier, 2013, 2014). When faces varied significantly in configuration, we found an index that was significantly larger than 1. The whole is important, at least in certain respects (Richler et al., 2012).

One thing we agree on is the power of testing hypotheses about perceptual and cognitive processes using computational models that can be evaluated quantitatively. Like many other areas of psychology, it is quite common in face recognition to support or reject mechanisms based on empirical evidence alone, with researchers making intuitive predictions about how complex mechanisms might behave without ever instantiating those mechanisms in models and generating valid predictions. This will not end the debate of course (e.g., Fific & Townsend, 2010; Mack et al., 2011; Ross, Deroche, & Palmeri, 2014; Silbert & Thomas, 2013; Wegner & Ingvalson, 2002), but at least by instantiating hypotheses computationally, we can focus those debates on well specified assumptions.

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