Visual Neuroscience: Computational Brain Dynamics of Face Processing

A recent study of how the brain processes emotionally expressive faces has revealed how task-relevant information is first gathered from the region around the eyes and then integrated downwards until categorization is achieved.

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Passport photos in the European Union and other countries are now required to conform to strict guidelines regarding the size, position and facial expression of the passport holder. The main reason for this is that current computational face recognition algorithms require such standardized visual material and are not very good at dealing with different views or expressions. This reflects our limited knowledge of the brain computations that underlie the human capacity to identify faces and extract information from them regarding parameters such as gaze direction or facial expression. Indeed, visual neuroscience has, over the last few decades, focused mainly on the study of brain responses to statically presented visual images in both humans and non-human primates. To make progress in unraveling the computational underpinnings of cognitive functions such as object or face recognition, however, will require the development of novel techniques that go beyond established standard methodology.

A paper published recently in *Current Biology* [1] reports on the results of just such a development. Using novel computational methodology, the authors have linked a specific brain event to the dynamics of visual categorization of facial expressions. Their results are based on the N170, a negative peak in the event-related brain potential occurring 170 milliseconds after stimulus onset [2,3]. Schyns *et al.* [1] demonstrate that this brain event reflects the systematic integration of information contained in face images, such that the eyes are processed first and information is subsequently added from lower face regions around nose and mouth. Interestingly, nose or mouth regions had an impact on the N170 only when this was necessary to disambiguate a particular emotional expression. The results show that, beyond localization of function, brain imaging signals can be used to reveal a sequential order in the processing of face features.

Schyns *et al.* [1] have applied classification image techniques [4] to behavioral as well as electroencephalographic (EEG) data. For behavioral data, this technique can determine which features of complex visual stimuli subjects are relying on to identify the stimuli or to assign them to categories. By exploring the stimulus dimensions of image space and spatial frequency, the authors were able to determine, for faces with one of five expressions, the diagnostic features required for the categorization of expression. A classification image summarizes the results for each expression. This reveals that wide-open eyes are crucial for ‘fear’, whereas a smiling mouth is diagnostic for ‘happy’, as shown in Figure 1A. While these behavioral results are not particularly surprising, they do demonstrate that the classification image technique can quantitatively determine which features of complex visual stimuli are used during a categorization task.

The application of the classification image technique to EEG brain potentials, however, yielded novel and highly intriguing results. Schyns *et al.* [1] focused on the N170, a brain potential that is well known to be modulated by face stimuli and occurs at occipito-temporal electrodes on the human head. Submitting the trial-by-trial EEG voltages during the time period of the N170 to the classification image analysis, they could estimate, with a high temporal resolution of 4 milliseconds, the features in the face stimuli that modulated brain activity during the N170. The dynamics of the EEG sensitivity to facial features revealed that the region near the eyes had an impact on the EEG earlier during the N170 than regions lower in the face near nose and mouth. This was true in general for all studied expressions; an example is shown in Figure 1B for the expression ‘happy’. The implication of this is that faces are processed by the brain in a series of sequential steps, with the eye region being processed first and lower regions in the face following later.

Interestingly, this downward integration occurred only when it was necessary for accurate behavioral judgments, and the integration was correlated with the latency of the N170 information peak. Thus, for the expression ‘fear’ regions near the eyes conveyed sufficient information and there was accordingly no downward integration required and the N170 for this expression peaked relatively early, at around 175 milliseconds. By contrast, the expression ‘happy’ did require downward integration as the mouth shape was of critical importance and accordingly the N170 peak occurred later, at around 185 milliseconds. This suggests that integration of information does not proceed automatically, but is instead subject to cognitive control processes that terminate the

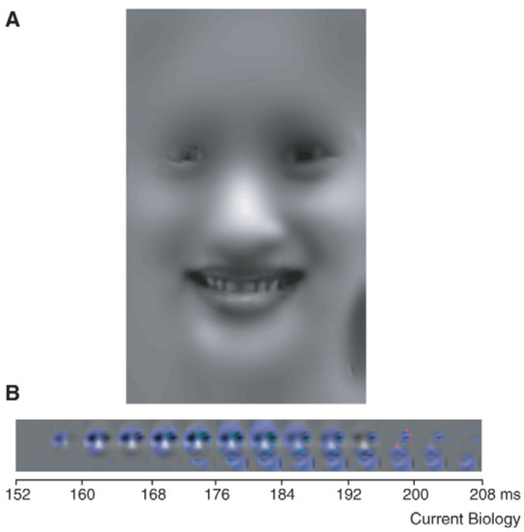

Figure 1. Dynamics of face processing.

(A) Classification image for the expression 'happy', showing that the eye region and the smiling mouth were crucial for behavioral categorization of this expression. (B) Temporal dynamics of sensitivity of the N170 brain potential to facial information for the expression 'happy' The blue color represents image features that had a strong influence on the N170 brain potential at each particular time point. A clear up-down progression is apparent in these blue regions, with regions near the eyes having a strong impact on the N170 earlier than regions near nose and mouth.

integration once the behavioral goal of classification has been achieved. The emerging picture is that face recognition proceeds along a series of steps, during which particular facial features are analyzed in a predetermined and fixed sequential order.

The study by Schyns *et al.* [1] is an innovative example of applying advanced computational techniques to study face recognition processes. Their classification image technique allows them to determine when a particular brain event is sensitive to perturbation of particular features in the visual image. This in turn provides insight into which features of the visual stimulus are processed at each point in time, the logic being that features whose perturbation do not affect the brain potentials are not currently being processed. As a technique, this approach can be seen as a refinement of decoding schemes that have been used by several groups to predict the stimulus currently being viewed based on the brain activity in sensory cortical regions registered with functional imaging [5,6]. Those studies have shown that the perception of a subject can be predicted on single trials when brain imaging data are analysed using appropriate computational algorithms. The classification image technique by contrast requires a large number of observation periods before insights into the strategy and information use of subjects can be gained.

An important challenge for future research is thus the introduction of adaptive methods, which could make classification image techniques dramatically more efficient by being able to consider measured brain responses online to modify the visual stimulus. Another intriguing aspect of the study by Schyns *et al.* [1] is that the integration of information appears to take place under cognitive control. The authors speculate that this might be achieved by interaction of occipital brain regions with the prefrontal cortex. Thus, the certainty about the categorization might be computed in prefrontal regions and depending on this, either a decision for one of the expressions would be made or further extraction of relevant features would be requested from occipital regions. This suggests a task-dependent flow of information between prefrontal and occipital cortices, where the regions communicate longer with each other in the case of more ambiguous facial expressions requiring integration such as 'happy', whereas for easy expressions such as 'fear' much less communication would be required. Neural responses to faces certainly exist in the prefrontal cortex [7], and there is also extensive evidence for the idea that effortful stimulus processing is associated with increased activity in the visual cortex [8–10]. Further research is surely required to clarify the role and interaction of brain regions involved in the face recognition process, but visual neuroscience is continuing to develop novel techniques that promise rapid progress in this direction.

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