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The Human Face as a Dynamic Tool for Social Communication

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As a highly social species, humans frequently exchange social information to support almost all facets of life. One of the richest and most powerful tools in social communication is the face, from which observers can quickly and easily make a number of inferences — about identity, gender, sex, age, race, ethnicity, sexual orientation, physical health, attractiveness, emotional state, personality traits, pain or physical pleasure, deception, and even social status. With the advent of the digital economy, increasing globalization and cultural integration, understanding precisely which face information supports social communication and which produces misunderstanding is central to the evolving needs of modern society (for example, in the design of socially interactive digital avatars and companion robots). Doing so is challenging, however, because the face can be thought of as comprising a high-dimensional, dynamic information space, and this impacts cognitive science and neuroimaging, and their broader applications in the digital economy. New opportunities to address this challenge are arising from the development of new methods and technologies, coupled with the emergence of a modern scientific culture that embraces cross-disciplinary approaches. Here, we briefly review one such approach that combines state-of-the-art computer graphics, psychophysics and vision science, cultural psychology and social cognition, and highlight the main knowledge advances it has generated. In the light of current developments, we provide a vision of the future directions in the field of human facial communication within and across cultures.

Introduction

As a highly social species [1], humans frequently engage in complex interactions to support the functioning of almost every facet of life — personal, familial or professional. Social interactions involve dynamically exchanging specific patterns of information to achieve a mutual understanding between two or more individuals, allowing each to adjust their cognitions and behaviors for adaptive action within a given culture or context. For example, successfully communicating threat, aggression or submission (agonistic behavior) typically prevents potentially harmful encounters, thereby benefitting all engaging in the interaction [2]. In contrast, a breakdown in communication — for example, difficulty in showing or identifying signs of emotion — can significantly impair social relations, resulting in an increased risk of social isolation [3–5], or even physical or mental harm. With subsequent migration across the world, increasing cognitive complexity [6] and cultural diversification, systems of social communication, much like languages [7], are both highly sophisticated and variable.

One of the richest and most powerful tools in social communication is the face. A brief look at any face demonstrates the numerous inferences observers can make about an individual — identity [8–12], gender/sex [13–15], age [16,17], race/ethnicity [18–20], sexual orientation [21–23], physical health [24,25], attractiveness [26,27], emotions [28–32], personality traits [33–35], pain [36] or physical pleasure [37], deception [38–40] and even social status (for example, in pigmentocracies [41]). Although humans quickly, and apparently effortlessly, perform such a variety of social categorizations on a daily basis [21,33,42], understanding the precise nature of this process — which specific face information subtends the perception of each category — remains challenging, because the face, as a transmitter of multiple and complex social categories, comprises a high-dimensional, dynamic information space (see also [43]).

Historically, attempts to understand the face as a social communication tool have stimulated nature *versus* nurture debates, from Darwin's groundbreaking theory of the evolutionary origins of facial expressions of emotion [28], to the Zeitgeist of cultural relativism (for example [44–49]), the more recent wave of cross-cultural recognition studies pioneered by Ekman (for example [50]; see [51–53] for reviews) and ontological theoretical developments [29–32,54–56] (see [57] for a review). Yet, whether facial expressions are biologically hardwired or socially learned, or their recognition is based on two (for example, valence and arousal [58]) or many (for example, value, novelty, pleasantness or legitimacy [59–61]) appraisal dimensions, understanding the face as a social communication tool requires identifying which specific face information elicits the perception of a specific social category, such as 'happy', 'female', 'white Caucasian' or 'attractive'.

To address these questions, traditional approaches have typically used theoretical knowledge or naturalistic observation to first select and test small sections of the high-dimensional face information space. A classic example is the universal facial expressions of emotion — 'happy', 'surprise', 'fear', 'disgust', 'anger' and 'sad' — which correspond to a small set of theoretically derived facial expressions that elicit above chance accuracy across cultures [50,62–68]. Although widely considered the gold

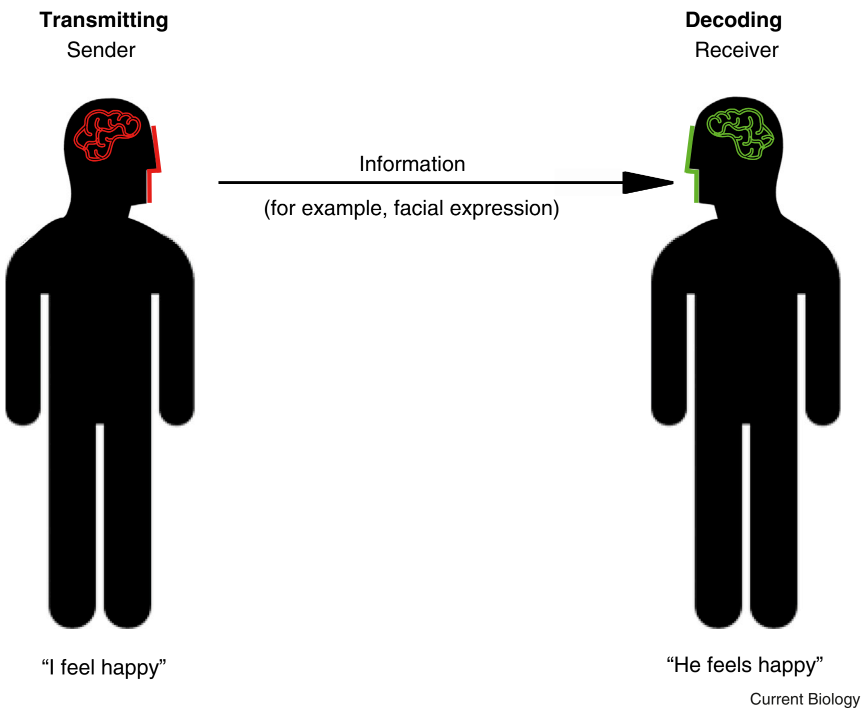

Figure 1. Information transmission and decoding framework.
Facial expressions, whether innate or learned, form part of a dynamical system of information transmission and decoding. Transmission: the sender encodes a message (here, 'I feel happy') as a form of information (for example, a facial expression, body movement, vocalization) and transmits it across a communication channel to the receiver (for example, a visual or auditory system). Decoding: to decode the incoming information, the receiver uses their prior knowledge (mental representation of category information) to extract task-relevant (diagnostic) features and perform an interpretation (categorical perception), typically resulting in a sufficiently accurate reconstruction of the message (here, 'he feels happy'). Adapted from [53] with permission from the publisher (Taylor & Francis Ltd, http://www.tandfonline.com).

standard in research [69–85], implicit acceptance of these (static) facial expressions not only curtails progress in characterizing the dynamic patterns of facial expressions (see [86] for a review), but also in broadening knowledge of more intricate social categories — for example, 'irritated', 'delighted', 'confused', 'skeptical' — that support our complex everyday social interactions. Consequently, and in contrast to detailed knowledge we have gained of social communication in other species — for example, the alarm calls of the vervet monkey [87] or the waggle dance of the honeybee [88] — a precise characterization of the face as a social communication tool remains to be addressed.

With advances in digital technologies and experimental methods, and the broadening of a scientific culture that embraces cross-disciplinary approaches, exploring the complexities of the face as a dynamic transmitter of social information is now an empirical reality. To mark this new chapter and build a vision of the future directions in the field of facial communication, our review has the following aims. First, to illustrate the challenges of understanding the face (a complex dynamical system) as a tool for social communication. Second, to demonstrate new interdisciplinary approaches that combine methods imported from traditionally distinct fields — for example, psychophysics, vision science, dynamic computer graphics, information theory, social cognition and cultural psychology — to overcome these challenges. And third, to review recent work that has used such methods to advance understanding in facial communication. Finally, we consider future directions by highlighting new and remaining key questions.

A Dynamic System for Transmitting and Decoding Information

To illustrate the challenge of understanding the face as a dynamic tool in social interaction, it is useful first to consider the process of social communication. At an abstract level, social communication is, like many other communication systems in humans (for example, telephone, television, satellites), other animals (for example [89]), plants (for example [90]) or bacteria (for example [91]), a dynamic system involving the transmission and decoding of information. Figure 1 illustrates the main components of such a general communication system.

As discussed in behavioral ethology [2,92], psychology [93] and engineering [94], *communication* is the act of *information transfer*, in which one individual sends information that modulates the behavior of another, thereby reducing uncertainty. Specifically, as shown in Figure 1, the sender encodes the message (here, 'I feel happy') as a form of information — for example, a facial expression, body movement or vocalization — and transmits it across a communication channel to a receiver. To decode the incoming information, the receiver must use their prior knowledge (their mental representations of category information) to extract relevant (diagnostic) features (for example, [95]) and perform an interpretation (categorical perception). When communication is successful, the receiver reconstructs the message with sufficient accuracy and extracts a meaning, in this case, 'he feels happy'. Understanding a system of communication therefore requires precisely identifying which transmitted information elicits a particular response in the receiver.

Importantly, the act of communication — providing information about the environment (but see [96] for deception) — depends on a number of conditions. Firstly, the information transmitted must be detectable by the receiver; for example, the retinal receptor density of the human eye allows detection of detailed visual information only at relatively short distances. Therefore, increasing distances between sender and receiver would diminish the detectability of relevant face information, such as that conveyed by the sclera, and the recognition of an associated social category — in the case of the sclera, 'fear' [83]. Such receiver characteristics force communication to rely on other sources to transmit detectable information across longer distances, for example, voice or body movements [97].

Secondly, for communication to succeed, the receiver must associate the detected information pattern, for example, the sclera, with a perceptual category — prior knowledge, whether acquired or hard-wired, here 'fear' — and its associated meaning in a given culture or context. Communication tends to breakdown when the transmitted information is unknown to the receiver — for example, only certain medical professionals associate specific facial movements with underlying neurological conditions [98] — or where sender and receiver do not share the same meaning associated with the information pattern. For example, the 'thumbs up' gesture means 'OK' in Western countries, but is a phallic insult in the Middle East (see [48,49,99] for more examples of cross-cultural confusions and mismatching). Thus, understanding the characteristics of the receiver's mechanism (see also [100] for environmental factors) — detection capabilities, stored information patterns and their associated meanings — can inform the patterns of information it is designed to capture to support social communication (but see also superstimuli [101]). In recognizing the fundamental link between information production and perception, Darwin used the receiver's perceptual response (emotion categorization) to investigate the universality of facial expressions of emotion, an approach that would dominate the field for over a century.

Thirdly, communication largely depends on the reliability (honesty) of the information transmitted and sender/receiver advantages. For example, sending information that reliably manipulates the behavior of others, or receiving reliable predictions about the environment, both support adaptive action. However, the transmission of dishonest information and sender/receiver disadvantages is regularly observed in communication [102]. Thus, communication comprises three distinct forms: *signalling*, such as reliable fearful facial expressions [103,104]; *cueing*, such as when skin color indicates caste/social status; and *coercion*, such as the mimicry of genuine Duchenne smiles. Such distinctions, applicable to both animal and human communication, highlight the intricacies of understanding the phylogenetic and ontogenetic evolutionary bases (within a culture) and communicatory function (veridical, deceptive or involuntary) of transferred information.

Finally, the act of communication — sending information to modulate another's behavior — can be deliberate, such as a greeting smile, or unintentional, as in blushing, which indicate uncontrolled anxiety. Identifying which specific aspects of the face — morphology, complexion, dynamics — can be used to intentionally manipulate others' behavior, and which produces involuntary, fixed, and possibly inconcealable information, is central to understanding *how* the face is used to optimize success within an ecological niche. For example, a specific facial expression such a smile (voluntarily produced information) could dampen the negative social impressions from an untrustworthy looking facial morphology (involuntarily produced information).

In all such cases — honesty or deception, volitional or forced, advantageous or detrimental — identifying the specific face information that subtends the perception of specific social categories is essential to understanding the system of social communication. However, a major challenge to this endeavor is that the face is a high-dimensional, dynamic information space.

A High-dimensional Dynamic Information Space

There are three main dimensions of facial variation: dynamics, morphology and complexion. Firstly, the human face is equipped with a large number of independent striated muscles, under voluntary control [105], each of which can be combined and activated at different levels of intensity over time. Consequently, the face is capable of generating a high number of complex dynamic facial expression patterns. Secondly, facial morphology (shape and structure) varies across multiple dimensions, including face width, height, brow ridge and cheek-bone prominence, jaw width, inter-eye distance, mouth width, lip thickness, forehead height, and so on [106,107]. Thirdly, complexion — comprising color, for example, pigmentation [108] or pallor/redness, and texture, for example, wrinkles, scarring, cutaneous conditions, adiposity — provides yet another potential source of information.

Another salient platform for social communication is provided by facial adornments: cosmetics/painting, tattooing, piercing, jewelry, hair, clothing and teeth sharpening/blackening are widely used to indicate social status or group alliances, or accentuate beauty (by enhancing or camouflaging morphological or textural face features [109]). As a result of these variations, every one of the 106 billion humans [110] that has ever walked the earth has possessed a unique face (and one that has changes across his or her lifetime), a point that brings home the high level of objective information the face can transmit.

To advance the science of social communication and inform socially intelligent and culturally aware avatars and companion robots with precise knowledge of social information [111–117], it is necessary to objectively identify the low-dimensional face information, for example, facial expression patterns, that subtends different social judgments, and we shall consider how this may be done in the next section.

Theoretical and Empirical Approaches to Social Communication

As mentioned above, classic approaches to understanding the face as a communication tool typically used theoretical knowledge or naturalistic observations to select and test a very small portion of the high-dimensional face information space. Although undoubtedly influential, such approaches can cast a relatively narrow light on the question, as we will now illustrate (see also [51,53,118] for further discussion).

Most notably, based on Darwin's groundbreaking theory of the biological and evolutionary origins of facial expressions of emotion (see also [103,119]), pioneering work by Ekman proposed a specific set of facial expressions as universally communicating six basic emotions across all cultures. Each of these facial expressions comprised a theoretically derived facial movement pattern (see [120] for prototypes and major variants) described according to the Facial Action Coding System (FACS) [121] — an objective system that comprehensively describes all visible facial movements called Action Units (AUs) [122]. For example, 'happy' comprises AU6 (Cheek Raiser) and AU12 (Lip Corner Puller), whereas 'sad' comprises AU1 (Inner Brow Raiser), AU4 (Brow Lowerer) and AU15 (Lip Corner Depressor). In a series of cross-cultural recognition studies (for example [29,50,63,65,68,123]), these specific facial expressions, the AU patterns, consistently elicited above chance recognition performance across different cultures.

Subsequently, the field largely concluded that these specific AU patterns universally communicate six basic emotions across all cultures (see [69] for a review) with resulting stimulus sets (for example [124–129]) fast becoming the gold standard across broad fields including cultural (for example [69–71]), clinical (for example [72,73]), developmental (for example [74]) and health psychology (for example [75]), neuroscience (for example [76–81]), perception and visual cognition (for example [82–84]) and computational modelling (for example [85]).

However, in addition to a criterion (>16% recognition accuracy) that does not reflect reliable communication and potentially masks cultural differences (for example AU patterns for ‘fear’ and ‘disgust’ consistently elicit significantly lower recognition accuracy in non-Western cultures [50,62–68]; see [130] for a review), the conclusions provided little impetus to consider or test other AU patterns for basic emotion communication. Consequently, knowledge of facial expressions of emotion remained restricted to a small set of static AU patterns that communicate only six emotions mostly in Western culture (a small proportion of the human population, see [131]). Yet, to precisely identify the dynamic AU patterns that communicate emotions, or other relevant social categories such as personality traits or mental states, within and between cultures requires a thorough exploration of the high combinatorics of dynamic AUs — a major empirical challenge that requires a systematic data-driven approach.

Psychophysical Laws of Social Perception

One way of addressing this challenge is to import the successful methods and knowledge of psychophysics, a field that aims to characterize the relationship between objectively measurable information in the external environment (physical stimuli) and its interpretation by an observer (subjective perception). Thus, by deriving psychophysical laws (for example [132–134]), psychophysical methods typically simplify complex, high-dimensional stimulus information to the few dimensions that subtend perception: they perform a dimensionality reduction. For example, a model observer performing the low-level visual task of discriminating left from right oriented Gabor patches near contrast threshold will require information about three parameters: input orientation, contrast and spatial frequency. A parametric design examining these three dimensions would produce a thorough understanding of how the model observer’s visual system resolves the task, with the contribution of each dimension to perceptual decisions modeled within the framework of statistical decision theory [135,136].

As indicated above, however, psychophysically probing the receptive fields of social face perception (high level vision) immediately presents a considerable challenge [137,138]. Relative to the dimensions of simple Gabor patches, however, conjecturing which dimensions of complex, natural face information — dynamics, morphology, complexion or a combination of the three — to probe is disproportionately more complicated, with each dimension constituting an explicit hypothesis about the nature of the categorization task. Because the theoretical and empirical stakes are high when selecting and exploring dimension(s) of face information, combining theoretical and empirical knowledge of social face communication can help guide experimental design.

To illustrate this, consider judgments of physical attractiveness, which could relate to judgments of mating or parenting potential. Mating potential relies on identifying a healthy opposite sex individual, communicated by genetically determined, and thus relatively fixed, aspects of the face, such as symmetry and complexion [25,139], and sex differences in morphology, such as jaw and brow ridge prominence [140]. In contrast, parenting potential might depend more on judgments of behavioral intentions such as trustworthiness or warmth, as communicated by more transient and voluntarily controlled face information such as facial expressions (for example [141]). Thus, psychophysics could be used to sample information from each potentially relevant dimension of the face — complexion and dynamics - and measure the receiver’s subjective response, thereby deriving the psychophysical laws of social perception, in this case, of long-term partnering or one night stand potential [142,143].

To directly illustrate the successful application of psychophysics to exploring dimensions of face information, we will return to our previous example of facial expressions of emotion (dynamics). Consider that we aim to identify which facial expressions communicate ‘rapid danger’ and ‘distant danger’ in a largely unknown culture (for example, the Sentinelese people). With no *a priori* knowledge, or assumptions, of these facial expressions, psychophysical methods can be used to sample the dynamic dimension of the face (their dynamic AU patterns) and measure the receiver’s subjective response (categorical perception).

Figure 2 illustrates such an approach using an example trial. On each experimental trial, a computer graphics Generative Face Grammar (GFG) platform [144] randomly samples from the relevant face dimension — the dynamic AU information space. In this illustrative trial, a biologically plausible combination of three AUs is randomly selected from a core set of 42 AUs (AU5 — Upper Lid Raiser color-coded in red, AU9 — Nose Wrinkler in green and AU12 — Lip Corner Puller in blue). The GFG then assigns a random movement to each AU by selecting random values for each of six temporal parameters (onset, acceleration, peak amplitude, peak latency, deceleration and offset; see color-coded curves). The dynamic AUs are then combined to produce a photo-realistic random facial movement, illustrated here with four snapshots (see Movie S1 in the Supplemental Information). The naïve receiver categorizes the stimulus as meaningful (here, ‘rapid danger’) at a given level of intensity (here, ‘strong’) if the synchronies of random face movements correlate with their perceptual expectations (mental representation) of ‘rapid danger’ at ‘strong’ intensity; if the pattern does not correspond to either category, ‘rapid danger’ or ‘distant danger’, the receiver selects ‘other’.

Over many such trials, we obtain a distribution of the relationships between specific dynamic AU patterns — segments of the high-dimensional information space called the categorization manifold — and the receiver’s perceptual response. Statistical analysis of these relationships, broadly referred to as reverse correlation [145], can reveal the dynamic AU patterns that reliably communicate to the receiver ‘rapid danger’ and ‘distant danger’ at different levels of intensity. In doing so, we can derive the psychophysical laws of high-level constructs as they relate to the physical aspects of the face. Repeating the same experiment

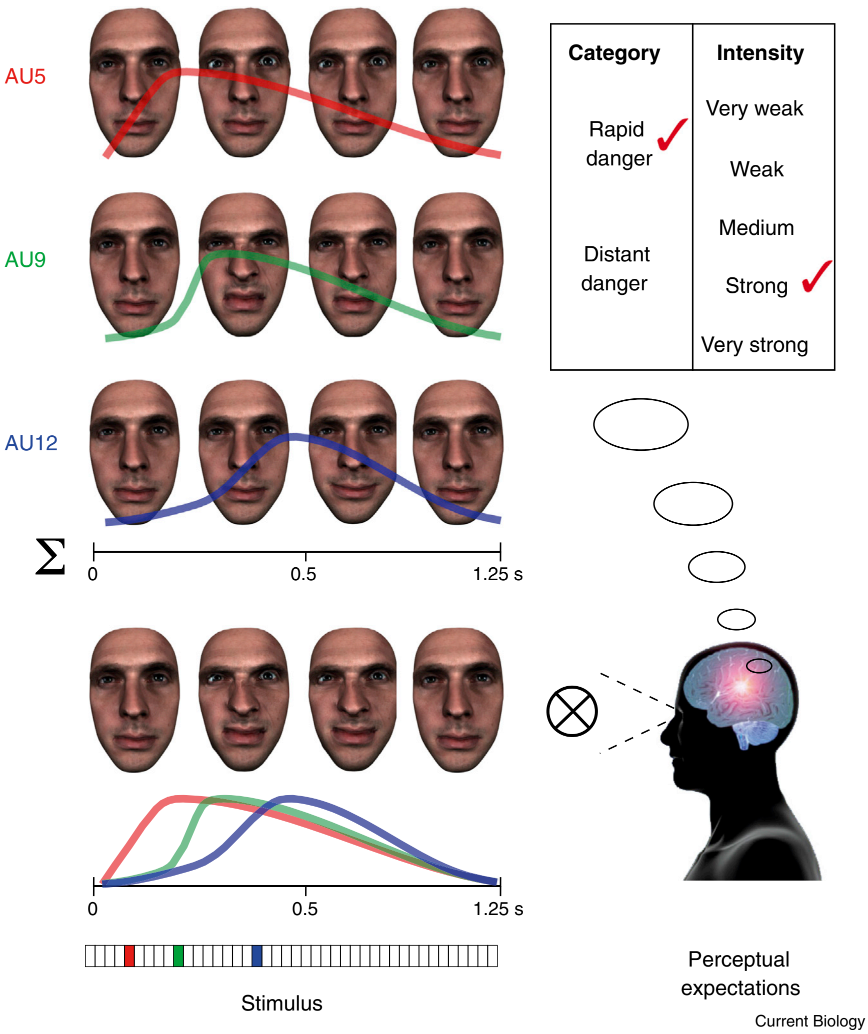

Figure 2. Stimulus generation and task procedure.
Stimulus: on each experimental trial, a Generative Face Grammar (GFG) [145] randomly selects from a core set of 42 Action Units (AUs) [122] a subset of AUs (AU5 — Upper Lid Raiser color-coded in red, AU9 — Nose Wrinkler in green, and AU12 — Lip Corner Puller in blue) and assigns a random movement to each (see color-coded curves). The randomly activated AUs are then combined to produce a photorealistic random face movement, illustrated here with four snapshots (see also Movie S1 in the Supplemental Information). Perceptual expectations: the naïve receiver interprets the stimulus as expressive (here 'rapid danger,' 'strong' intensity) if the random face movements form an information pattern that correlates with their perceptual expectations (mental representation) of 'rapid danger', 'strong' intensity (otherwise selecting 'other'). Adapted with permission from [147].

in different cultures (Western and East Asian, or different socio-economic classes, or age groups) could then reveal whether the dynamic facial expressions are similar or different, and if so, how.

Whether applied to the individual dimensions of dynamics, complexion or morphology, or their combination, the strength and broad potential of psychophysics is that it can, in principle, model any face information that communicates perceptual categories. This could include basic or complex emotions such as 'happy', 'contempt', 'panic' or 'fury' [146,147], social traits such as 'competent', 'dominant', 'attractive' or 'trustworthy' [141,148,149], mental states such as 'thinking', 'bored', 'confused' or 'doubtful' [150–152], genuine and fake happiness, sadness, or guilt, masculinity and femininity, pain and pleasure, sick and healthy [153,154], young and old [17], individual identity, and so forth (and including parameters of intensity, when applicable).

Such statistical relationships between dimensions of the face information space and the receiver's perceptual judgment can be univariate, thereby reducing the high-dimensional information space to those that communicate a specific meaning (for example, 'rapid danger'), or multivariate, which can capture synchronies of information such as AU conjunctions over time and structure the diagnostic dimensions of the categorization manifold. Consequently, deriving the psychophysical laws of social perception can provide both the syntax of dynamic information, which could also constrain the algorithms (computational procedure) subtending human and artificial perception of different social categories, for example, by informing the specific temporal order for the coding and integration of the components of information for each social category.

We will now briefly consider recent work that has used psychophysical methods to explore two dimensions of face information, dynamics and morphology, to identify the dynamic facial expressions that communicate the key social categories of emotions and social traits.

Cultural Specificities in Dynamic Facial Expressions of Emotion

Facial expressions provide visually salient dynamic patterns of information to communicate emotions (see also [155,156] for information from voice and [157] for information from body posture). With biological and evolutionary origins [103,119], the six basic facial expressions of emotion have largely been considered universal. Yet, differences in recognition accuracy across cultures [50,62–68] and proposed culture-specific accents/dialects [49,158,159] question the true extent of universality (see also [51,160] for reviews). Although cultural specificities in facial expressions of emotion are widely discussed [29,161–163], knowledge of which facial expressions communicate emotions within and across cultures is largely limited to static (typically posed) facial expressions [124,127,128,159] that are recognized primarily in Western culture (see [62–64,67]).

To address this knowledge gap, we used the GFG (Figure 2) to psychophysically model the dynamic facial expressions of the six classic emotions in Western Caucasian and East Asian

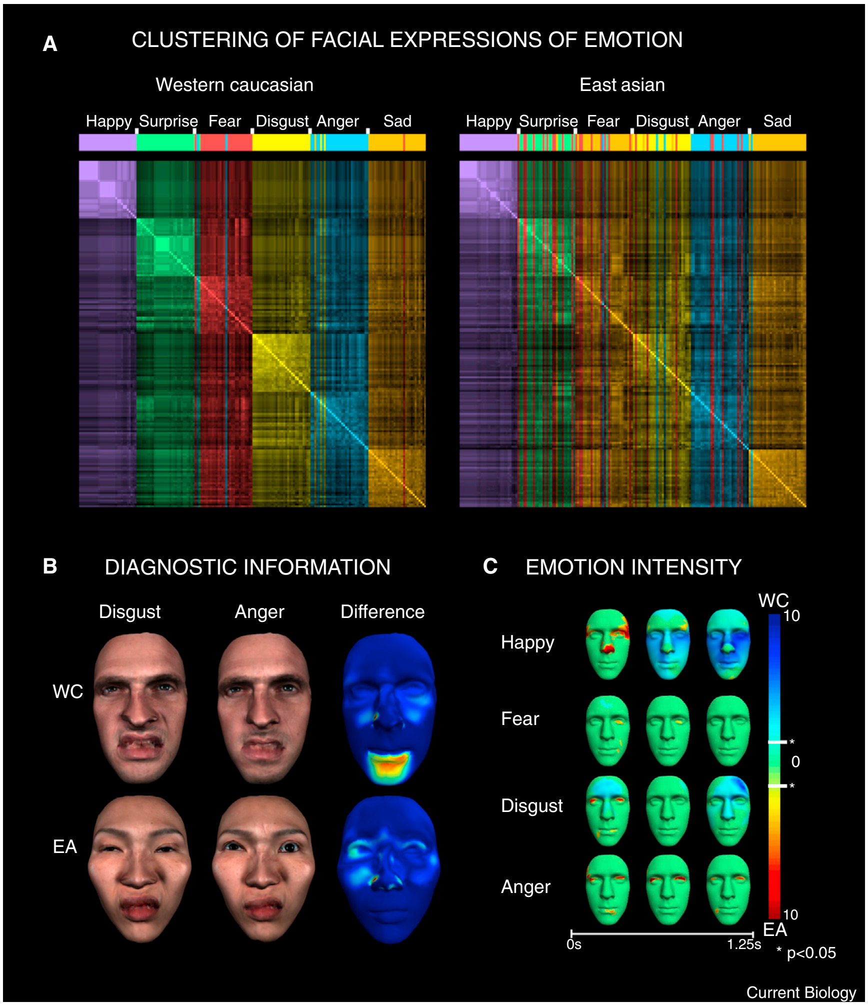

Figure 3. Cultural specificities in dynamic facial expressions of emotion.
(A) Clustering of facial expressions of emotion. For each culture, Western Caucasian (WC) and East Asian (EA), vertical color coded bars show the cluster membership of each facial expression model (represented as a 42 x 1 dimensional vector detailing the AU pattern) as labeled — 'happy', 'surprise', 'fear', 'disgust', 'anger' and 'sad' (30 models per emotion category and culture). The underlying gray-scale similarity matrix shows the similarity between model pairs, where lighter squares indicate high similarity, darker squares low similarity. Note in the WC group, lighter squares along the diagonal indicate higher model similarity within each of the six emotion categories compared with the EA models. Correspondingly, k-means cluster analysis shows that the WC models form six emotionally homogenous clusters (for example, all 30 'happy' WC facial expression models comprise a single cluster, color-coded in purple). In contrast, the EA facial expression models show overlap between emotion categories, particularly for 'surprise', 'fear', 'disgust', 'anger', and 'sad' (note their heterogeneous color coding). (B) Diagnostic information. WC and EA models show that different face regions distinguish certain emotions (here, 'disgust' and 'anger'). In WC models (top row), the mouth is more informative to distinguish 'disgust' and 'anger' (note the difference in the mouth region of the face identity maps, and the corresponding color-coded difference map). In EA models (bottom row), the eyes are more informative — note the narrowing of the eyes in 'disgust' compared to the salient eye whites in 'anger' (see also corresponding face identity and difference map). (C) Emotion intensity. For four emotions, color-coded face maps at three time points show the spatio-temporal location of expressive features conveying emotional intensity. Blue indicates WC-specific dynamic face patterns; red indicates EA-specific dynamic face patterns where values represent the t-statistic ($p < 0.05$). Note for the EA models (red colored regions), emotional intensity is communicated with early eye region activity. Adapted with permission from [147].

culture, revealing three main differences [147], with the results shown in Figure 3.

Panel A of Figure 3 shows the clustering of facial expressions of emotion: using a combination of k-means cluster analysis and Mutual Information [164], Western Caucasian models form six distinct and emotionally homogeneous clusters — high *within*-category facial expression similarity and low *between*-category facial expression similarity (for example, all 30 Western Caucasian 'happy' facial expression models comprise a single cluster, color-coded purple) — revealing a distinct and culturally shared representation of each emotion. In contrast, East Asian models tend to overlap between certain emotion categories (note the heterogeneous color-coding of the facial expression models of 'surprise', 'fear', 'disgust' and 'anger'), reflecting a culture-specific departure from the common view that human emotion communication is comprised of six universally represented basic categories (for example [165]).

Panel B of Figure 3 shows diagnostic information: Western Caucasian (top row) and East Asian (bottom row) facial expressions show that different face movements distinguish certain emotions (here, 'disgust' and 'anger'). As shown across the individual texture maps, and corresponding color-coded difference maps, the mouth is more informative in the Western Caucasian facial expressions of 'disgust' and 'anger', whereas the eyes are more informative in the same East Asian facial expressions (note the narrowing of the eyes in 'disgust' compared to the salient eye whites in 'anger' (see also [67,166,167] for culture-specific use of the eyes and mouth).

Panel C of Figure 3 shows emotion intensity: Western Caucasian and East Asian facial expressions also show differences in the dynamic communication of emotional intensity. Illustrated here with four facial expressions of emotion — 'happy', 'fear', 'disgust', and 'anger' — color-coded face maps show the culture-specific face features that convey emotional intensity across time. For example, early red colored areas show that East Asian individuals primarily use early eye region activity to convey emotional intensity, a finding that is mirrored by East Asian emoticons, where (^.^) represents happy and (>.<) represents angry.

By mapping the relationship between the dynamic AU information space and the perception of the six classic emotion categories in different cultures, we precisely characterized cultural specificities in facial expressions of emotion, questioning notions of universality. Given that the complexities of human emotion

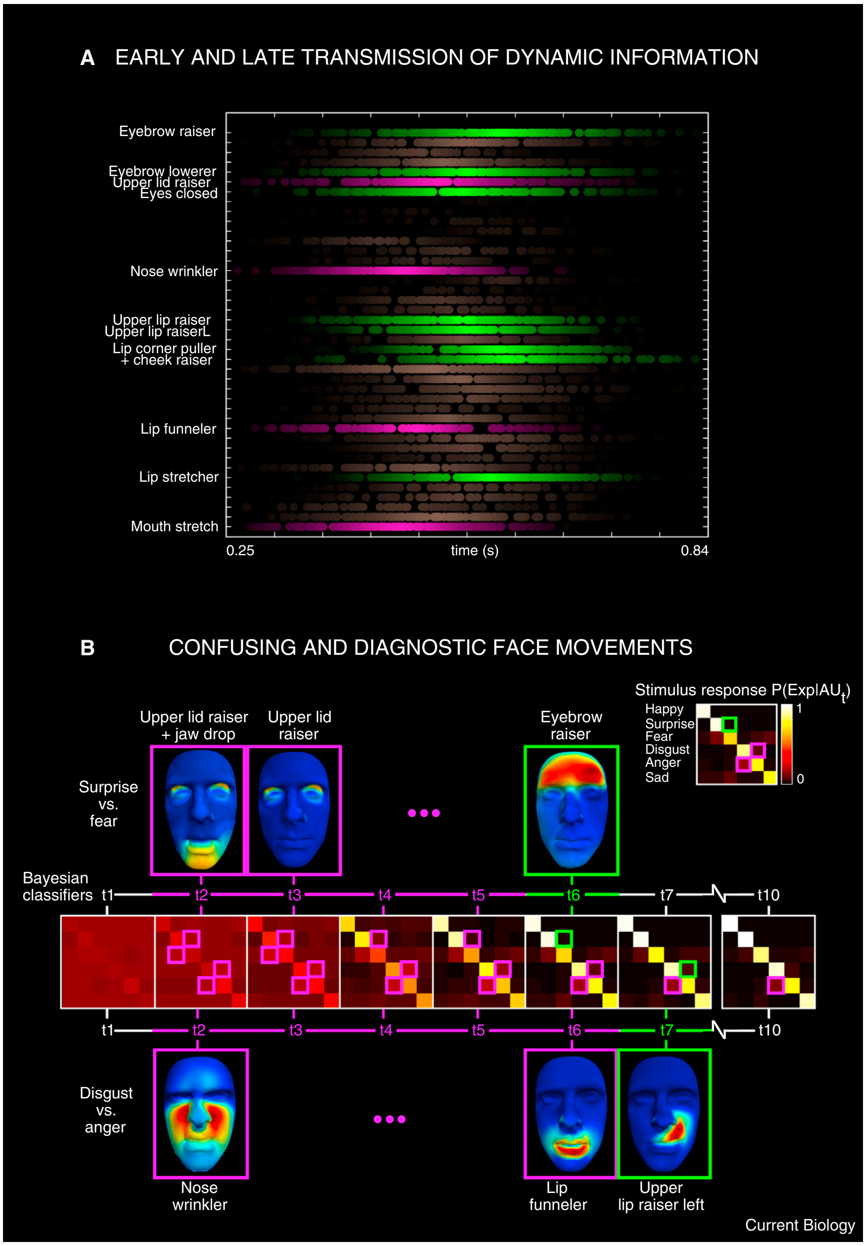

Figure 4. Hierarchical transmission of dynamic face information over time.
(A) Early and late transmission of dynamic information. In each row, color-coded circles show the distribution of peak latencies for each AU (see labels on left) for all facial expression models (120 models per emotion category). Brightness indicates distance to the median peak latency (weighted by the proportion of models with that AU). Facial expressions of emotion are characterized by the early transmission of few biologically rooted AUs, color-coded in magenta (for example, Upper Lid Raiser, Nose Wrinkler; $p < 0.05$), followed by the later transmission of AUs typically diagnostic for the six classic emotions, color-coded in green (for example, Brow Raiser, Upper Lip Raiser; $p < 0.05$). (B) Confusing and diagnostic face movements. Bayesian classifiers applied to dynamic facial expression models across time (t1–10) show that early confusions (see magenta squares in confusion matrices) are due to the common transmission of certain AUs, such as Upper Lid Raiser in Surprise *versus* Fear (see color-coded deviation maps outlined in magenta from t2–t5), and Nose Wrinkler in Disgust *versus* Anger, from t2–t6). Later transmissions of diagnostic AUs support the categorization of all six emotions (for example, 'surprise' transmits Brow Raiser (t6) distinguishing it from 'fear'; 'disgust' is discriminated from 'anger' due to the transmission of Upper Lip Raiser Left (t7). See also Movie S2 in the Supplemental Information. Adapted with permission from [168].

communication require a number of nuanced emotion categories, for example, 'fury', 'delighted', 'contempt' or 'panic', extending the range of dynamic facial expressions of emotion across cultures [146] could further refine the characterization of cultural commonalities and differences in emotion communication.

Hierarchical Transmission of Dynamic Face Information Over Time

Rather than comprising all-or-nothing displays, facial expressions are orchestrated dynamic patterns that unfold over time. Because facial expressions of emotion are largely evolved signals, adapted from their original biological function to serve social communication [28,103,119], understanding how and why specific face information is transmitted over time, their syntactical 'design', could reveal further knowledge of their communicatory function. For example, whereas eye widening and nostril flaring, typical of fear facial expressions, facilitate the flight response, for example, by identifying escape routes and optimizing muscle function, wrinkling the nose and narrowing the eyes, typical of disgust facial expressions, provide an effective strategy for protecting against the entry of pathogens. As adaptive behaviors that benefit the expresser [103], these biologically-rooted face movements probably evolved as rapid movements to enhance their physiological function. Consequently, the facial expressions used by modern man to support social communication could comprise an embedded set of early, elemental face movements on which social and culture specific information is later grafted to refine meaning. Analysis of dynamic models of the six classic facial expressions of emotion indeed shows an intriguing hierarchical transmission of information over time, reflecting a more complex communication system that supports a series of successive and increasingly refined categorizations [168]. The data are illustrated in Figure 4.

Panel A of Figure 4 shows early and late transmission of dynamic information: In each row, color-coded circles show the distribution of peak latencies for each AU over time for all facial expression models. The early transmission of dynamic face information is characterized by few, biologically rooted AUs (for example Nose Wrinkler and Upper Lid Raiser, color-coded in magenta) [103], whereas later transmissions (color-coded in green) comprise AUs typically diagnostic for the six classic emotions (for example, Brow Raiser and Upper Lip Raiser) [84].

Panel B shows confusing and diagnostic face movements: Using Bayesian classifiers applied to the dynamic facial expressions over time, the early transmission of certain AUs supports the categorization of fewer emotion categories. For example, both ‘surprise’ and ‘fear’ transmit Upper Lid Raiser early in the dynamics, resulting in their early confusion. Later in the dynamics, the transmission of diagnostic AUs results in the discrimination of all six emotion categories. For example, ‘surprise’ transmits the Brow Raiser later, which distinguishes it from ‘fear’ (see also Movie S2 in the Supplemental Information for a similar pattern with ‘disgust’ and ‘anger’).

Analysis of the syntax of dynamic face patterns shows that facial expressions of emotion are perceptually segmented across time and follow a hierarchical evolution from biologically basic to socially specific, thereby questioning the view that human emotion communication comprises six basic, psychologically irreducible categories. In line with biological signalling predictions, early face movements also show characteristics of detectability, such as the sudden appearance of the high contrast eye whites (a feature unique to humans [169]) and nose wrinkling typical of danger signals [170], each of which could act as salient ‘attention grabbers’ [171,172] to facilitate the perceptual processing of socially relevant information (for example, see [104] for eye gaze). Thus, precisely examining the unfolding of dynamic facial expressions across time reveals that early and late facial information could perform functionally different roles in social communication.

Psychophysical methods can thus be used to precisely characterize the syntactical design of dynamic facial expressions of emotion, which could be broadened to examine other more subtle emotions, for example, ‘irritation’, ‘delighted’ or ‘shame’, or other forms of dynamic social communication, such as genuine and fake smiles [39], social traits, such as trustworthiness or dominance, or mental states, such as ‘confusion’, ‘doubt’ or ‘interest’, in a culturally sensitive manner. Modelling the perceptual expectations of individual observers of different cultures, for example, in clinical and typical populations, could also inform the sources of communication breakdown, for example, where expectations of temporal order are violated, and inform the development of therapeutic interventions.

Dynamic Face Information Transiently Camouflages Social Trait Impressions From Facial Morphology

Successfully negotiating social situations involves communicating not only transient emotional states, but also stable traits such as trustworthiness, dominance or attractiveness, with important consequences for individuals. This can be important, for example, in mate choice [27,173], occupational [174] or educational opportunities [175], sentencing decisions [176,177], and the behavior of groups (for example, voting preference [42,178]). Across the animal kingdom, specific facial displays are used to strategically alter the perceptions and subsequent behaviors of others, for example, subordinates, prey, or predators, thereby increasing one’s chances of success within an ecological niche. As an example, high status rhesus monkeys display specific facial expressions to communicate their rank to subordinates in the animal hierarchy [179]. Although certain human face morphologies are strongly associated with specific social traits such as attractiveness, dominance and trustworthiness [149,180], specific patterns of face movements can strategically camouflage these default social impressions, thereby manipulating the social judgments of others.

Using psychophysical methods, we have shown that facial expressions trump morphology in the perception of social traits. Figure 5 demonstrates the results using two social traits, dominance and trustworthiness, as illustrative examples. Each color-coded face map shows the dynamic AU patterns associated with the perception of each social trait (dominance and trustworthiness). We then applied each dynamic mask to different face morphologies that were previously rated as the opposite social trait; for example, we applied a dominant dynamic mask to submissive face morphologies. Social trait judgments of the resulting faces showed that the dynamic masks transiently camouflage the default social trait impressions conveyed by phenotypic facial morphology. For example, a face previously judged as highly submissive produced a rating of highly dominant when displaying a dominant facial expression [141].

An intriguing source of inequality is also shown: whereas dynamic masks of dominance and trustworthiness easily override the effects of our genes (for example, the actor Anthony Hopkins can convincingly portray either a psychopathic cannibal or a loyal butler), attractiveness, where phenotype dominates, is the most difficult to camouflage with dynamic masks, which is why fashion/beauty models comprise a niche group. Thus, while individuals can display specific facial expressions to flexibly manipulate social perceptions of trustworthiness and dominance to their advantage, regardless of their inherited facial morphology, perceptions of attractiveness, a relevant factor for mating potential and gene transmission, remain relatively robust to dynamic mask camouflaging.

In this review we have explained how psychophysical methods can be applied to understanding how different dimensions of face information, dynamics and morphology, each contribute to social perception, providing new opportunities to address key questions. For example, to elicit judgments of trustworthiness, must out-group members, indicated, for example, by skin color, display more intense facial expressions of trustworthiness than in-group members? How does voluntary face information such as facial expressions (a potential tool for deception) and involuntary, fixed and inconcealable face information such as skin color contribute to social judgments? Modelling the contribution of different dimensions of face information in relation to the receiver’s internal knowledge, including perceptual biases such as racial stereotyping [148] and theory of mind, can therefore further reveal the complexities of social communication within and between different groups.

Conclusions

We have illustrated the challenges to understanding the human face as a dynamic transmitter of social information, presented psychophysical methods designed to address this challenge — parametric sampling of face information coupled with subjective perception to derive the psychophysical laws of social perception — and recent work demonstrating the strengths of this approach. Earlier models of face recognition

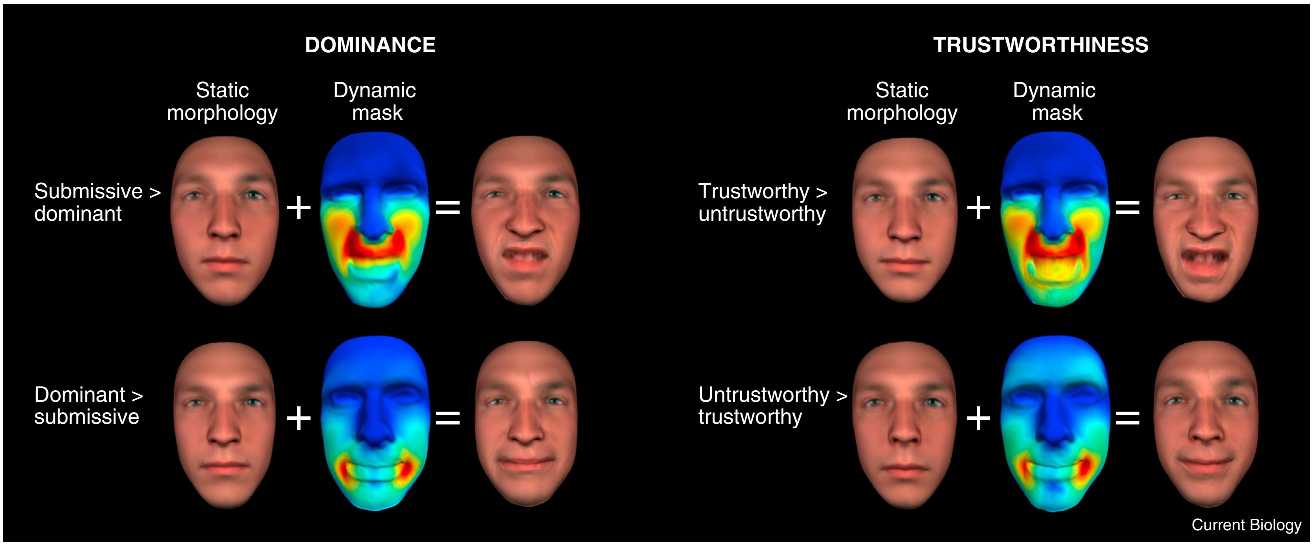

Figure 5. Dynamic face information transiently camouflages social trait impressions from facial morphology.
Here, we use two social traits, dominance and trustworthiness, as examples to illustrate the perceptual effect of applying a dynamic social mask to different face morphologies. Dominance: the Static Morphology represents an average of male identities judged as highly submissive (–ve dominance). The color-coded Dynamic Mask shows the face movements associated with judgments of high dominance. When added to the Static Morphology, the Dynamic Mask transforms the social judgments of the face from submissive to dominant. As shown in Dominant > Submissive, the same transformation occurs when a submissive Dynamic Mask is added to a dominant Static Morphology. Trustworthiness: the Static Morphology represents an average of male identities judged as highly trustworthy. The color-coded Dynamic Mask shows the face movements associated with judgments of low trustworthiness. When added to the Static Morphology, the Dynamic Mask transforms social judgments of the face from trustworthy to untrustworthy. As shown in Untrustworthy > Trustworthy, the same transformation occurs when a trustworthy Dynamic Mask is added to an untrustworthy Static Morphology.

[181] considered that different social categorizations such as identity, expression, gender, and ethnicity rely on separate information processing streams. Now, current knowledge shows that complex interactions between different dimensions of face information, for example, dynamics, morphology and/or complexion, subtend social perception. For example, while certain face morphologies are strongly associated with certain social traits such as trustworthiness or dominance, specific facial expressions can be used to camouflage this information, thereby manipulating social trait impressions.

Using the face to transmit information for social communication is typically achieved within specific contexts, where the same face information (for example, tightly squeezed eyes, bared teeth) can have different meanings (winning, losing, pleasure or pain) when combined with additional sources of information such as body movements, vocalizations, clothing or scenery (see [182–184] for reviews). As with exploring the high-dimensional information space of the face, precisely identifying which contextual information — vocalizations, body posture, movements or shape, clothing and hairstyles, in and outdoor scenes, weather, season or time of day, buildings, occasion, culture and so on — contributes to different social categorizations presents an additional, much greater challenge. Because social communication (and perception generally) can involve the integration of information from multiple high-dimensional information spaces, exploring this hyperspace of multi-sensory information presents a genuinely ambitious feat. To begin to address this challenge, we have demonstrated the strengths and potential of psychophysics to parametrically manipulate and combine different information sources to derive the psychophysical laws of social perception.

With the emergence of a new digital economy, it is increasingly important to equip new technologies — for example, web-based facilities designed for cross-cultural communication, socially interactive avatars and companion robots — with detailed knowledge of human social communication. Using objective methods to derive such knowledge — for example, which facial expressions communicate the same meaning across cultures, and those that generate confusion — can be installed and used for the accurate recognition and adaptive display of culture-appropriate or universally understood social information. Web-based facilities for human communication could analyze the face of each participant, identify potentially confusing face movements — for example, using the eyes to show emotional intensity in East Asian culture [147] — and provide real time on-screen translations for other-culture participants where necessary. Similarly, companion robots could adjust their facial structure, complexion and dynamics to suit a specific role or context, such as displaying more signs of trustworthiness when greeting guests, or dominance when guarding a property.

Finally, although the nature *versus* nurture debate has provided substantial empirical and theoretical impetus (particularly in emotion communication), modern research now aims to understand the symbiotic relationship between biology and environment: "genes are expressed *through* the environment, and not independently of it" [185]. Thus, understanding social communication within an ecological (cultural) niche also requires examination of how different physical environments — for example, mountainous or flat landscapes, differing light exposure — have shaped sender and receiver apparatus (the face and visual system), which could reveal the extent and impact of genetic differences on social communication (the nature component). On the other hand, visual perception remains a fundamentally subjective experience that is realized and shaped by acquired conceptual knowledge. For example, cultural differences in learning specific 'feature vocabularies' corresponding to a given perceptual category (concept) could facilitate or hinder learning of new culture-specific categories [186,187]. By identifying the feature vocabularies that subtend social communication over the lifespan and in different cultures could further inform how the transmission and decoding of information is achieved (or challenged) across cultural boundaries.

To embrace the true complexity of the task, one thing is certain: understanding the system of human social communication — the dynamic transmission of information using rich and complex sources (face, body, voice, scenes), and decoding based on biologically constrained apparatus (the eye, visual brain) coupled with prior knowledge (whether acquired or hardwired) — relies on the strategic interdisciplinary convergence of knowledge from broader fields including vision science and psychophysics, cognitive psychology, cultural and social psychology, anthropology, biology, information theory and engineering. With the emergence of a new scientific culture that embraces such interdisciplinary approaches, the field of human social communication is poised to experience a new chapter of progress and exciting discoveries.

SUPPLEMENTAL INFORMATION

Supplemental Information includes two movies and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2015.05.052.

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