The role of facial movements in emotion recognition

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Abstract

Most past research has relied on the use of static facial expressions, typically photographs of posed expressions intended to depict the apex of the emotional display. Whilst these studies have provided important insights into how emotions are perceived in the face, they necessarily leave out any role of dynamic information. After outlining major findings using static expressions, we review evidence from various fields to ask *what* dynamic information offers in comparison to static images and *when, how,* and *why* this information matters in emotion recognition. Besides the added value of spatial/ form-related cues, we show that dynamic displays offer distinctive temporal information such as the direction, quality, and speed of movement. When kept in their original, unmodified form these characteristic temporal patterns enhance the judgement of facial affect, thereby involving higher-level cognitive processes that engage complex networks of brain areas and guide a range of social and emotional inferences. The positive influence is most evident in suboptimal conditions when observers are impaired and/or facial expressions are degraded or subtle. Dynamic displays further recruit early attentional and motivational resources in the perceiver, facilitating the prompt detection and prediction of others' emotional states, with benefits for social interaction through enhanced simulation/mimicry and emotional contagion. As emotions can be expressed in a variety of modalities, we finally examine the multimodal integration of dynamic/static cues across different channels. Directions for future research as well as open questions and remaining challenges are discussed.

Keywords: dynamics, motion, temporal, emotion, facial expression, face.

Introduction

Compared to other species, humans are capable of moving their faces in a wide variety of ways (Vick, Waller, Parr, Smith Pasqualini, & Bard, 2007). This dynamic quality of facial behaviour makes the human face a powerful medium for emotion communication. With over forty different facial muscles that can be activated alone or in combination (Ekman, Friesen, & Hager, 2002), it conveys a wealth of information critical for detecting and interpreting facial expressions. Since most faces we encounter and interact with move, it is reasonable to assume that we are highly attuned to motion cues (Gibson, 1966). Hence, humans should be particularly sensitive to expressive movements. In line with this notion, dynamic displays are found to evoke greater perceptual realism and judgmental confidence (Ambadar et al., 2005; Lederman et al., 2007; Weyers et al., 2006; Zloteanu, Krumhuber, & Richardson, 2018), probably because they are ecologically more valid representations of the behaviour seen in everyday life (Johnston, Mayes, Hughes, & Young, 2013; Paulmann, Jessen, & Kotz, 2009; Trautmann, Fehr, & Herrmann, 2009).

Yet, the vast majority of studies to date have relied on static pictures of faces. According to a recent survey, only 13% of articles published in psychology between 2000 and 2020 employed dynamic stimuli for investigating emotion/expression-related questions (Dawel et al., 2021). Such imbalance may stem from methodological challenges in stimulus generation. Clearly, static displays can be tightly controlled, thereby minimising extraneous sources of image variation. However, these do not typically capture the dynamic complexity present in a human face (Sato et al., 2004). As such, they may miss potentially important cues for emotion recognition. There is now compelling evidence that movement improves the ability to extract emotion-relevant content from faces (Krumhuber et al., 2013; Krumhuber & Skora, 2016). Motivated by the need to explain this dynamic advantage, research efforts on the temporal dynamics of facial expressions have been growing steadily. As a result, our scientific understanding has substantially improved in recent years, with reviews and quantitative meta-analyses focusing on various aspects of dynamic face and expression recognition (Dobs et al., 2018; Zinckenko et al. 2018; Lander & Butcher, 2020; Arsalidou et al., 2011). Nonetheless, a multi-method synthesis of the literature that seeks to identify key mechanisms has been lacking to date.

In this Review, we provide an overview of the literature that combines evidence from multiple fields (such as vision science, affective/emotion science, and neuroscience) to ask what dynamic displays offer in comparison to static images. Clearly, faces convey via static and dynamic cues a wealth of information other than emotion, such as identity, visually derived semantic information (objective properties like age and sex, as well as subjective judgements like honesty), gaze and visual speech (Bruce & Young, 2012). This Review focuses on the processes underlying emotion recognition, and in particular the recognition of dynamic facial expressions. We seek to explore the specific qualities of facial expressive movements and *what* those add to emotion recognition. For a deeper understanding of the mechanisms behind the processing of dynamic displays, we further ask *when, how, and why* such information matters. These questions are fundamental in explaining the dynamic advantage and why static stimuli potentially miss relevant aspects inherent in real-world expressions.

To this end, we first outline major findings on emotion recognition from studies using still images to establish what has been learnt from static expressions. This short summary serves as a baseline for comparison from which to review the critical role of moving displays. Given that faces are usually accompanied by vocal sounds and body movements, we then examine the multimodal integration of dynamic/static cues across different channels, thereby focusing on evidence beyond the face. Finally, we discuss some of the open questions and remaining challenges, including future work needed to address them.

Static emotion recognition

Static images of faces act as the foundation for the psychological study of emotion recognition (Darwin, 1872). By portraying the peak of the emotional display, they capture differences in facial behaviour resulting from inherently dynamic muscle-driven morphological changes. Previous research has shown that observers can recognise with 70-90% accuracy a limited set of 'basic emotions', including happiness, anger, sadness, disgust, fear and surprise, which are expressed by distinct patterns of facial movement (Ekman, 1992, 1999; Goeleven et al., 2008; Langner et al., 2010; Palermo & Coltheart, 2004; Tottenham, Tanaka, Leon, McCarry, et al., 2009; Tracy & Robins, 2008). While the exact nature and number, and even existence, of basic emotions remains subject of considerable debate and criticism (Ortony, 2022; Russell, 2017; Russell & Fernández-Dols, 1997), these can be divided into subcategories or combined into families and form a large variety of blends (Jack, Sun, Delis, Garrod, & Schyns, 2016; Keltner, Sauter, Tracy and Cowen, 2019; Schmidtmann et al., 2020). From all emotions happiness is the most easily identifiable in the face, whereas fear and disgust are recognised worst and often mistaken for surprise and anger, respectively (Calvo & Lundqvist, 2008; Palermo & Coltheart, 2004; Tottenham, Tanaka, Leon, Mccarry, et al., 2009). In general, recognition accuracy varies as a function of the number and type of expressions included and is lower when response formats are free (than enforced) and expressions are spontaneous (than posed) (Elfenbein & Ambady, 2002; Haidt & Keltner, 1999; Kayyal & Russell, 2013; Wagner, 1997).

For the recognition of basic emotions, local regions of the face can be as good as the whole face (Beaudry et al., 2014; Boucher & Ekman, 1975; Calder, Keane, et al., 2000; Smith et al., 2005; Tanaka et al., 2012), with specific areas benefitting different expressions (Blais et al., 2017; Yitzhak et al., 2021). For example, the eyes and upper half of the face are more useful in the recognition of fear, anger, and sadness, whereas the mouth and bottom half are better for identifying happiness, neutrality, and disgust. Interestingly, performance drops due to face inversion (upside-down faces) are relatively small for many expressions as compared to identity recognition, suggesting that local features can suffice in some circumstances for emotion discrimination (Calvo & Nummenmaa, 2008; Derntl et al., 2009; Psalta & Andrews, 2014). These features can be conceptualised in terms of localised facial muscle actions – so-called action units (Ekman et al., 2002) - which convey emotional meaning mostly in combination (Boucher & Ekman, 1975; Kohler et al., 2004; Wallbott, 1998b). As the same action units can appear in multiple expressions, emotion recognition necessarily also depends on non-local information. For example, fear and surprise share raised eyebrows (action units 1+2), but the presence of brow lowering (action unit 4) would imply fear, while a jaw drop (action unit 26) indicates surprise. Reflecting these non-local dependencies there is evidence that facial expressions can be processed holistically. In particular, composite faces (where top and bottom half show different emotions) interfere with the recognition of either half separately, suggesting that perceptual mechanisms rely on the spatial interdependency between expressive features of a face (Calder, Keane, et al., 2000; Palermo et al., 2011; White, 2000).

With static images, muscle movements cannot be seen in real time and need to be inferred. Low level image properties like the curvature of contours can signal different facial expressions as shown by studies with line-drawn faces (Etcoff & Magee, 1992; Horstmann, 2009; Hugdahl et al., 1989). This two-dimensional (2D) shape information is captured in the 2D position of facial landmarks (for example, the corners of lips and eyes), and supports expression recognition when other surface-based information (conveyed by greyscale differences in photographs) is kept constant (Sormaz et al., 2016). Exaggerating differences in 2D shape enhances the distinctiveness and emotional intensity of expressions, making them faster to recognise (Calder et al., 1997; Calder, Rowland, et al., 2000). To date, a variety of statistical analyses and neural network models have been applied to static images and related to human performance (Calder et al., 2001; Dailey et al., 2002; Susskind et al., 2007). Together, these data indicate that some aspects of human perception (emotion categorisation, similarity, recognition difficulty) can emerge from physical patterns of expression variation independent of affective meaning (Calvo & Nummenmaa, 2016).

In summary, the study of static images has profoundly shaped the scientific understanding of facial emotion recognition, demonstrating high levels of agreement at least for a limited number of basic emotions. While local regions of the face can be as important as the whole face, evidence also points towards holistic processes in expression recognition. Using static images, this line of work has revealed distinct patterns of expression variation and 2D shape information relevant for detecting, identifying, and classifying emotions.

Dynamic emotion recognition

In considering the potential benefit of facial motion, it is important to ask what the study of dynamic expressions adds to existing knowledge. For example, we can question whether dynamic information offers additional utility on top of static aspects, and if so, what extra information is processed. For this purpose, a synthesis of findings is presented that taps into key concepts in terms of *what* can be learnt about emotion perception from dynamic stimuli that is lacking in static images.

Spatiotemporal information

When seeing a moving face, *spatial information* is available about the underlying structure of the viewed expression; in addition, dynamic information is available about the way the face moves. Movement may facilitate the perception of its 3D structure, however the mathematical analysis of this 'structure-from-motion' process typically assumes rigid head motion (Ullman, 1979; O'Toole, Roark & Abdi, 2002), which is at odds with the elastic facial movements displayed in emotion expression (Black & Yacoob, 1997; Horowitz & Pentland, 1991; Torrensani, Hertzmann & Bregler, 2008). Nonetheless, according to recent work structure-from-motion information is also available from non-rigid movements (Jensen, Doest, Aanæs & Del Bue, 2021). Converging evidence suggests that dynamic expressions are more salient than static emotional faces (Biele & Grabowska, 2006; Uono, Sata & Toichi, 2009), with temporal motion itself aiding recognition. Dynamic information includes both *temporal and kinematic cues* (displacement over time, velocity, acceleration; Dobs et al., 2018; Sowden et al. 2021; FIG. 1). Work with point-light displays has demonstrated the importance of isolated kinematic information for the recognition of emotion (Johannson, 1973; Atkinson, Vuong & Smithson, 2012). Specifically, dynamic point-light displays of emotion are recognised above chance-level and more accurately than static ones (Bassili, 1978, 1979; Dittrich, 1991; Pollick et al., 2003; Atkinson et al., 2012; Bidet-Ildei, Decatoire & Gil, 2020). Exaggerating or changing the temporal characteristics of point-light displays critically affects their interpretation (Pollick et al., 2003; Furl et al., 2020; Keating et al., 2021). Dynamic expressions may also be represented in memory with respect to individually developed spatiotemporal norms (Furl et al., 2020; see also Valentine, 1991). Consequently, static expression recognition can be thought of as a 'snapshot' embedded within an inherently dynamic process (Freyd, 1987; Blais et al., 2012).

To identify the most informative visual aspects of facial movement different techniques can be used, allowing only certain aspects of the face to be seen. For example, 'bubbles' display specific visual information from parts of the face (Gosselin & Schyns, 2001; Royer et al., 2015). With the 'freezing' technique, areas of the face are selectively frozen whilst other parts move normally (Nusseck, Cunningham, Wallraven & Bülthoff, 2008; Back, Ropar & Mitchell, 2007; Back, Jordan & Thomas, 2009). These reveal that the mouth moves the most and may be particularly informative for the recognition of emotion (Blais et al., 2012, 2017; Hoffman et al., 2013). Interestingly, it may be that more time is spent on fixating the *centre of the face* (around the nose; Blais et al., 2017; Buchan, Parè & Munhall, 2007) when stimuli are dynamic than static. As biological motion can be processed outside the fovea (Gurnsey, Roddy, Ouhnana & Troje, 2008; Thompson, Hansen, Hess, & Troje, 2007), such visual strategy would allow motion information to be prioritised and optimally extracted from across the main areas of the face (Blais et al., 2017; Plouffe-Demers et al., 2019), facilitating expression recognition. Alternatively, there may be enhanced attention to different regions of the face dependent on expression (Calvo, Fernández-Martín, Gutiérrez-Garcia & Lundqvist, 2018).

Seeing a face move may also allow for the integration of various parts or *components* of the face into a whole across time (Anaki, Boyd & Moscovitch, 2007; Luo et al., 2015). While a clear definition of component information (as separable local elements such as eyes, mouth, or nose, Carey & Diamond, 1977; Sergent, 1984) is still missing in the literature, it contrasts with configural information, which refers to the spatial relationships between these elements (for reviews, see Rakover, 2002; Schwaninger, Carbon, & Leder, 2003; also see holistic hypothesis, Tanaka & Farah, 1993). Interestingly, the distinction between component and configural information, although well explored in static emotion recognition, is not well understood in the context of moving faces. Current evidence suggests that dynamic expressions are processed holistically (Favelle et al., 2015; Zhao & Bülthoff, 2017) but that the recognition advantage is unlikely to stem from enhanced holistic processing of dynamic compared to static stimuli

(Ambadar et al., 2005; Chiller-Glaus et al., 2011; Tobin, Favelle & Palermo, 2016). Instead, facial motion may enhance feature-based processing (for at least some expressions).

In sum, there is extensive evidence to support the usefulness of dynamic information in emotion recognition. Seeing a face move may increase the perceptual salience of the face, optimise visual strategies, and help temporally integrate information across different areas of the face. Nonetheless, it doesn't seem to be the case that movement of the face simply aids configural or holistic processing. Rather, distinctive temporal information is key.

Distinctive temporal information

Dynamic expressions comprise *multiple images*, thus offering additional information that is not included in a single static display (even when presented for the same duration). Clearly, denser sampling is beneficial, with higher frame rates of an expression (evolving from neutral to peak) facilitating its meaning and recognition (Bould, Morris, & Wink, 2008; Schultz et al., 2013). However, the dynamic advantage is not simply due to the extra static-based information contained in a sequence (TABLE 1). When presenting the same number of images (thus maintaining the informational content) but with visual noise masks in-between to interrupt the apparent motion, accuracy is significantly reduced for multi-static compared to dynamic sequences (Ambadar et al., 2005; Bould & Morris, 2008; Krumhuber & Manstead, 2009). Increasing the length of the noise masks (from 200 ms to 1000 ms) further disrupts the motion signal, worsening recognition performance (Bould & Morris, 2008). Facial dynamics therefore seem to provide a functionally distinct type of information that is independent from the quantity of static cues (morphology, form, shape) available.

Observing expressions unfold in time may increase sensitivity to changes in facial feature composition, similar to shifts in the perception between first-last images of a sequence (Ambadar et al., 2005). However, the effect of motion goes beyond the mere detection of expressional changes (Bould, Morris, & Wink, 2008). A critical component lies in the *directionality of change*. Time, unlike space, has a characteristic direction, allowing unique insights into the temporal trajectory of expressive displays. Recent evidence suggests that facial expressions unfold in a sequential (rather than simultaneous) fashion, transmitting patterns of signals over time (Jack et al., 2014; Jack & Schyns, 2015; Krumhuber & Scherer, 2011; Fiorentini, Schmidt, & Viviani, 2012; With & Kaiser, 2011). Observers are sensitive to the temporal structure of emotional expressions (particularly during their emergence, Leonard et al., 1991), and can reproduce the correct progression from a set of images showing different stages of the expression (Edwards, 1998).

Facial dynamics

When the natural temporal direction is distorted, for example by *randomizing the order* of frames within a video, recognition performance of dynamic displays significantly decreases (Cunningham & Wallraven, 2009b; Schultz et al., 2013; see also Takehara, Saruyama, & Suzuki, 2017, for low emotional intensity). In fact, image shuffling has such negative consequences that single static images carry more emotion-discriminative information (Plouffe-Demers et al., 2019; Richoz, Lao, Pascalis, & Caldara, 2018). As the number of frames that are kept intact increases (from 2 to 4 images as preserved unit within a video), the easier it becomes to identify the expression (Cunningham & Wallraven, 2009b). Together, these findings suggest that the benefits afforded by facial dynamics are unlikely to be due to the mere presence of motion signals. Instead, information about the temporal structure (directionality) inherent in dynamic displays appears to be a key aspect in emotion perception, allowing for predictable transitions between facial signals consistent with the preceding movement trajectory (Furl et al., 2010).

Further evidence in support of this notion comes from studies on *timeline reversal*. Every expression has an onset, a peak, and an offset phase. Reversing the temporal order by playing videos backwards leads to atypical facial motion trajectories with different emotional meanings (Reinl & Bartels, 2015, 2014). As such, natural onset and reversed offset expressions are not equivalent since both phases follow different timelines. While there is no perceptual priority for facial expressions that unfold simultaneously versus sequentially (Wehrle, Kaiser, Schmidt, & Scherer, 2000), deviations from the original timeline impair emotion attribution (Cunningham & Wallraven, 2009b; Korolkova, 2018; Sato, Kochiyama, & Yoshikawa, 2010; Delis et al., 2016). Furthermore, the affective quality varies with the temporal sequence of facial actions, producing different emotion connotations for the same expression (Krumhuber & Scherer, 2016).

Besides the temporal status of emotionally expressive displays, the *quality of motion* plays an important role. Natural facial movement typically follows nonlinear trajectories in which shifts in geometric vertex motion occur at different points in time. That is, dynamic transitions from the first to the last frame of a video are not constant but asynchronous and variable, with velocity changes in the movements of facial areas over time (Korolkova, 2018; Cosker et al., 2010, 2015). Unfortunately, the stimulus production procedure most often used to study facial motion perception is linear morphing or interpolation (Bould, Morris, & Wink, 2008; Furl et al., 2010; Hoffmann et al., 2010; Kamachi et al., 2001; Sato & Yoshikawa, 2004). Gradually morphing between two images yields highly controlled blends with smooth dynamic transitions. However, those lack the characteristic patterns of nonlinear (naturally deforming) motion, exerting a negative impact on expression perception when compared to natural facial dynamics (Wallraven et al., 2008; Cosker et al., 2010). In a similar vein, movement sequences with unpredictable or disrupted rhythm significantly impede performance (Bould, Morris, & Wink, 2008; Perdikis et al., 2017). While natural timing is not necessary for all face parts, dynamic sequences are preferred that approximate the original time course (Dobs et al., 2014).

Finally, the *speed* with which the face moves is an aspect inherent in dynamic displays. Changing the velocity of facial expressions by speeding up or slowing down the actual movement significantly affects recognition accuracy. Interestingly, the outcome of such manipulation varies between emotions based on differences in their intrinsic velocities. Among the basic six emotions sadness is naturally the slowest (Sowden et al., 2021). Hence, lower speed facilitates the recognition of sad expressions, whereas it impairs the correct identification of other emotions such as happiness or surprise (Recio, Schacht, & Sommer, 2013; Pollick, Hill, Calder, & Paterson, 2003). The effect of velocity is independent from viewing time (exposure duration), suggesting that movement speed uniquely characterizes distinct emotions (Bould, Morris, & Wink, 2008; Kamachi et al., 2001). In addition, it allows a differentiation between posed and spontaneous expressions (Hess & Kleck, 1994; Ambadar, Cohn, & Reed, 2009), with shorter onset and offset timings leading to less positive evaluations (Hoffmann et al., 2010; Sato & Yoshikawa, 2004; Krumhuber & Kappas, 2005; Krumhuber et al., 2007a, 2007b, 2009).

To sum up, there is converging evidence that facial dynamics convey meaningful information for emotion classification that goes beyond the mere detection of observable static features. The fact that observers are sensitive to those temporal properties - direction, quality, speed - points toward a perceptual system that is more complex and time-sensitive than previously assumed on the basis of static images.

Mechanisms of dynamic emotion recognition

For a deeper understanding of the mechanisms involved in dynamic emotion recognition, it is useful to consider the interrelated questions of *how, when*, and *why* dynamic information is important. By doing so, unique insights are gained into the role played by facial movement in emotion processing.

How dynamic information matters

Dynamic displays give rise to distinct percepts with unique information. But how does movement confer its benefits? In what ways does it impact emotion recognition? While the effects of facial motion seem to be largely perceptual (stimulus-driven), the inferences drawn from timing are associated with *higher-level cognitive processes*. For example, for a message to be decoded efficiently observers typically need to rely on prior knowledge to extract the relevant information (Jack & Schyns, 2015). Reverse correlation methods reveal that temporal parameters are part of people's mental representations, driving variations in their emotion ratings (Delis et al., 2016; Yu, Garrod, & Schyns, 2012). Hence, it seems that facial movements form an information pattern that is compared with perceptual expectations for each expression. These dynamic mental representations not only guide emotion recognition, but also influence the quality of emotion perceived.

Authenticity is such quality and reflects the degree to which an emotion is genuinely experienced (Krumhuber & Skora, 2016). Numerous evidence suggests that posed and spontaneous expressions differ in their temporal properties (such as duration, onset/offset speed, smoothness) (Hess & Kleck, 1990; Cohn & Schmidt, 2004; Schmidt, Bhattacharya, & Denlinger, 2009; Schmidt, Ambadar, Cohn, & Reed, 2006; Namba et al., 2016). Observers are sensitive to the dynamic trajectory when interpreting the meaning of facial expressions, with incorrect timings (in terms of speed, quality, and direction) resulting in lower perceived naturalness, genuineness, spontaneity, typicality, and convincingness (Sato & Yoshikawa, 2004; Cosker et al., 2015; Perdikis et al., 2017; Krumhuber & Kappas, 2005; Krumhuber, Manstead, & Kappas, 2007b; Krumhuber et al., 2009; Reinl & Bartels, 2015; Wallraven et al., 2008). Given that motion kinematics are rich with information about the emotion-eliciting event, it is not surprising that the discriminability of posed versus spontaneous expressions is enhanced when seeing dynamic compared to static displays (Krumhuber & Manstead, 2009; Namba, Kabir, Miyatani, & Nakao, 2018; Zloteanu et al., 2018).

Further evidence suggests that facial dynamics communicate not only *emotional and mental states* (Back, Jordan, & Thomas, 2009; Hanley et al., 2013; Krumhuber et al., 2019), but also social traits such as attractiveness, trustworthiness, or dominance (Krumhuber, Manstead, & Kappas, 2007b; Krumhuber et al., 2009; Rubenstein, 2005). In fact, the social effects of dynamic expressions are so strong that they can override trait inferences based on static facial morphology (Gill et al., 2014). Facial movement also helps to regulate interpersonal relations by shaping behavioural intentions to approach or cooperate (Krumhuber et al., 2007a; Krumhuber et al., 2009; Bugental, 1986). Thus, it appears that observers distil a broad range of information from moving faces, which give rise to high-level impressions. If the expressive signal matches those rich internal (mental) representations, emotional and other types of inferences can be drawn fairly easily.

Facial dynamics

Neuroscientific studies suggest that the recognition benefits afforded by dynamic expressions may be underpinned by *stronger and more extensive activation* of relevant brain regions (FIG. 2). These concern the ventral pathway, including the occipito-temporal face-specific areas and the fusiform face area, which support low-level processing of largely invariant aspects of faces such as form or identity. Furthermore, activation is augmented in the dorsal pathway, which is composed of the posterior superior temporal sulcus and the inferior frontal gyrus, linked to processing changeable features, including facial motion such as gaze, mouth and head movements, and facial expressions (Arsalidou et al., 2011; Haxby et al., 2000; O'Toole et al., 2002; Pitcher et al., 2011, 2014). The involvement of the posterior superior temporal sulcus is particularly interesting due to its implication in higher-order socio-cognitive tasks, such as theory of mind and action understanding (intentions). Apart from providing richer visual input to the brain, dynamic expressions may thus automatically engage social cognition to a greater extent than static images (Pitcher et al., 2011; Schulz et al., 2013).

Dynamic faces also recruit a *larger network of areas* that static faces, including the insula, amygdala, motor and prefrontal regions, shown to be involved in sensorimotor processing and social-emotional recognition (Foley et al., 2017; Furl et al., 2013; Sato et al., 2010, 2019). This extensive activation implies that the perception of dynamic expressions is not limited to face processing, but rather engages a range of cognitive functions to extract socially and emotionally relevant information from moving faces. The network has been proposed to support emotion understanding through cognitive and motor representations of the observed expression, and to drive the evaluation of social characteristics such as trustworthiness (Sato et al., 2019; Trautmann-Lengsfeld et al., 2009, 2013). Furthermore, it accounts for corresponding emotional, physiological, or motor (mimicry) reactions in the observer, thereby facilitating interpersonal interaction (Arsalidou et al., 2011).

Lastly, moving expressions confer their benefits by inducing *longer and more distributed neural activity* compared to static faces. Specifically, facial motion provokes earlier activation proposed to reflect 'motivated attention' that facilitates the initial stages of visual encoding when expressions dynamically emerge from the face (Recio et al., 2011, 2014). This activity remains enhanced for longer compared to static expressions, likely reflecting an increased attentional demand for processing the complexity of changing features in moving faces (Perdikis et al., 2017; Recio et al., 2011, 2014; Wang & Yuan, 2021). The perception of dynamic expressions is also characterised by rapid and bidirectional connectivity patterns supporting the information exchange between core regions (those that process facial characteristics and identity) and regions of the distributed network (those that process the emotional content and meaning of faces; Sato, Kochiyama & Uono, 2015; Trautmann-Lengsfeld et al., 2013). This connectivity appears to be modulated by synchronised neural oscillations proposed to play a key role in information transfer and binding between brain regions for integrated perception (Foley et al., 2017); Donner & Siegel, 2011). The synchronised and rapid connectivity within that network may underpin the efficiency and proficiency integral to the recognition of dynamic expressions across contexts.

Together, these findings suggest that people form mental representations of facial motion, which influence not only the recognition but perceived quality (for example, authenticity) of emotion and subsequent trait inferences. This complexity in processing is evident at the neural level, with dynamic (vs. static) expressions evoking stronger, more extensive, and longer activation across a complex network involving higher-order socio-cognitive processes.

When dynamic information matters

Dynamic information supports expression recognition in a flexible way, optimising face perception particularly in tasks where static cues alone are *suboptimal or insufficient* (Xiao et al., 2014, TABLE 2). For example, when form information is reduced or deteriorated there may be greater reliance on emotion cues available from moving faces. Consequently, dynamics triumph in judgements of facial affect from stimuli that are degraded in shape, texture, or realism, such as line drawings, morphed sequences, point-light displays and synthetic animations (Atkinson et al., 2012; Cunningham & Wallraven, 2009; Dobs et al., 2018; Ehrlich et al., 2000; Kätsyri et al., 2008; Kätsyri & Sams, 2008; Plouffe-Demers et al. 2019; Wehrle et al., 2000; Wallraven et al., 2008). In a similar vein, temporal cues aid emotion recognition when viewing conditions are problematic or constrained. This effect applies even if the stimulus itself may be largely unimpaired (such as in upside-down or composite faces), with dynamic expressions resulting in better and faster recognition than static ones (Ambadar et al., 2005; Back et al., 2009; Blais et al., 2017; Bould & Morris, 2008; Chiller-Glaus et al., 2011; Fujimura & Suzuki, 2010; Hoffman et al., 2013; Plouffe-Demers et al., 2019; Tobin et al., 2016). Hence, seeing a face move helps to compensate for the lack of static-based cues to expression found when image quality is reduced or viewing conditions are impaired.

Insofar as displays are non-degraded, highly intense, or strongly indicative of felt affect, facial dynamics may not always improve emotion recognition and trait ratings (Ambadar et al., 2005; Barker et al., 2020; Bowdring et al., 2021; Graininger et al., 2015; Kätsyri & Sams, 2008; Nelson et al., 2013; Nelson & Russell, 2011; Trichas et al., 2017).

Similarly, time pressure makes it easier to extract emotional information from static expressions, which are already fully developed from the onset (Jiang et al., 2014). Interestingly, studies have also failed to find a dynamic advantage for stimulus durations that are longer than 1000 ms (Fiorentini & Viviani, 2011; Liang, Liu, Li, & Wang, 2018; Widen & Russell, 2015). Such extended presentation time might allow for an in-depth exploration of the stimulus, reducing the relative advantage due to motion. Finally, the benefits of motion are minimal or non-existent when emotion recognition is already high in static images (Gold et al., 2013; Kamachi et al., 2001; Kätsyri & Sams, 2008). Clearly, dynamic cues offer most information in recognition tasks that are complex. As such, facial motion typically facilitates the discriminability and identification of *confusable emotions* like fear and surprise or anger and disgust (Jack, Garrod, Yu, Caldara, & Schyns, 2012; Jack et al., 2014; Chung, Kim, Jung, & Kim, 2019). The benefit is particularly evident for *weakly expressed and non-basic emotions* (guilt, shame, embarrassment), which comprise subtler and more nuanced features (Ambadar et al., 2005; Yitzhak et al., 2018; Cassidy et al., 2015; Graininger et al., 2015). Here, useful information is gained, especially in conditions of uncertainty, by observing how the expression changes over time.

Finally, facial movement acts as a facilitative factor when *observers are impaired* in their ability to decipher emotion-relevant information. Limitations may be due to age or a clinical, developmental, or neurological disorder, with facial dynamics providing useful compensatory cues (Harwood, Hall, & Shinkfield,1999; Uono, Sato, & Toichi, 2010; Gepner, Deruelle, & Grynfeltt, 2001; Tardif, Lainé, Rodriguez, & Gepner, 2006). For older adults, age-related deficits in emotion recognition typically diminish with the dynamic, relative to static, presentation of stimuli, perhaps due to their greater expertise with and emotional salience of moving expressions (Isaacowitz & Stanley, 2011; Holland, Ebner, Lin & Samanez-Larkin, 2018; Krendl & Ambady, 2010; Ziaei, Arnold & Ebner, 2021). Clinical depression is associated with impairments in judging facial expressions (Csukly et al., 2009; Langenecker et al., 2005; Persad & Polivy, 1993), although little work has directly compared dynamic versus static expression recognition by these patients. Since dynamic expressions are continuously changing, facial motion may provide sufficient distraction to suppress rumination, allowing patients to focus on the emotion at hand (Garrido-Vásquez et al., 2011).

For people with autism spectrum disorder the perception of biological motion is generally impaired (O'Brien et al., 2014; Todorova, Hatton & Pollick, 2019). However, moving faces can facilitate in some circumstances emotion recognition, especially when presentation speed is slow (Actis-Grosso et al., 2015; Jelili et al., 2021; Gepner, Deruelle &

Grynfeltt, 2001; Tardif et al., 2007). Neuropsychological studies further demonstrate preserved abilities for patients with brain lesions who are unable or impaired to identify emotions from still images, supporting the notion that static and dynamic faces are decoded by separate neural substrates (see 'how' section; Adolphs, Tranel & Damasio, 2003; Bennetts et al., 2015; Humphreys, Donnelly, & Riddoch, 1993; Longmore & Tree, 2013; Richoz, Jack, Garrod, Schyns, & Caldara, 2015). Such dissociation in brain pathways may invoke different perceptual skills, partly driving the recognition advantage of dynamic faces often observed in clinical populations.

To summarise, seeing a face move facilitates the identification of emotions particularly when recognition is difficult due to a lack of static based cues available from the face or when viewing conditions are non-optimal. Similarly, information provided by the way expressions change over time may help in conditions of uncertainty with high stimulus complexity or when observers are impaired in recognizing emotions from the face.

Why dynamic information matters

The processing of moving faces is of high evolutionary significance, providing survival-critical information (for example, friend or foe) beyond mere identity, including social cues related to threat or intentions. Consequently, dynamic expressions *receive attentional priority* in the visual system over static expressions, strongly biasing perception towards dynamic facial information once it is available (Pollux, Craddock & Guo, 2019). They also provoke earlier and prolonged activity in the visual system due to an increased demand for attentional resources to process facial movements (Recio, Sommer & Schacht, 2011). In the context of threat detection, this means that anger in a crowd of happy or friendly expressions is typically quicker to detect when seen in dynamic versus static form (Ceccarini & Caudek, 2013; Horstmann & Ansorge, 2009). Also, participants are sometimes faster in discriminating emotions from moving than static faces (Calvo, Avero, Fernandez-Martin & Recio, 2016; Recio, Sommer & Schacht, 2011). In addition to the reaction time advantage in emotion detection, the ecological significance of dynamic expressions tends to elongate time perception, making them appear to last longer, a phenomenon referred to as 'time-drag' effect (Li & Yuen, 2015). Such preferential processing of salient information (in particular, potential threat in the context of anger displays) allows for the preparation of an appropriate response. Together, this evidence suggests that moving faces activate early attentional processes and motivational resources, facilitating their perception and evaluation.

Facial dynamics

Since visual capabilities are optimised for motion signals, humans are highly sensitive to the temporal direction of the face (as reviewed in the 'what' section). Such tendency may reflect individuals' expectations about the emotion trajectory, thereby *biasing perception in a predictive fashion* (Furl et al., 2010; Reinl & Bartels, 2014). In line with predictive coding accounts, there is evidence that brain pathways involved with facial expression processing show stronger activation to deviations from the predictable, natural timeline. Thus, it appears that expectation violation imposes extra processing demands needed for evaluating unnatural sequences (Reinl & Bartels, 2014; Sato, Kochiyama & Yoshikawa, 2010; Schulz, Brockhaus, Bülthoff & Pilz, 2013; Trautmann-Lengsfeld et al., 2013).

Dynamics further matter because facial movements *make information more prominent* for social interaction. Noticeably, dynamic displays evoke more intense perceptions than their static versions (Biele & Grabowska, 2006; Rymarczyk et al., 2011, 2016a; Weyers, Mühlberger, Hefele & Pauli, 2006; Yoshikawa & Sato, 2008), which may stem from increased arousal attribution or attention allocation in response to natural motion (Weyers et al., 2006; Simmons et al, 1999). Indeed, the viewing of dynamic expressions is related to higher self-reported arousal (Sato, Fujimura, & Suzuki, 2008), a phenomenon proposed to elicit a corresponding emotional state in the observer to facilitate social communication (Sato & Yoshikawa, 2007). Additionally, intensity cues may aid expression identification in ambiguous cases. For example, intense laughter accompanied by frowning is often erroneously associated with maliciousness in static images, but correctly identified as a positive emotion in dynamic displays (Hoffmann, 2014).

The visual expertise with information encoded in unique temporal trajectories may also help observers to *predict the sender's emotional state*. For example, movement has the potential to induce representational momentum, whereby the presentation speed of dynamic displays intensifies the perceived endpoint of the expression (Yoshikawa & Sato, 2008). Such perceptual enhancement suggests that humans are highly attuned to the unfolding process; a mechanism which may facilitate the recognition of sudden changes in facial emotion. Similarly, probing paradigms indicate that dynamic displays lead to more efficient processing of subsequent faces, particularly when those are emotionally congruent. For example, a dynamic happy probe facilitates the subsequent identification of a happy face to a greater extent than a static probe (Kaufman & Johnston, 2014; Thornton & Kourzti, 2002). These findings corroborate the notion that facial movements activate predictive visual mechanisms, whereby the perception of a certain emotion biases subsequent processing in line with its direction. Comparable effects have been found for dynamic stimuli that are presented outside of conscious awareness. In particular, visually crowded or subliminal emotional faces can induce biases in evaluative judgments of subsequent neutral stimuli in the direction of the unconsciously presented dynamic expression (Kouider, Berthet & Faivre, 2013; Sato, Kubota & Toichi, 2014).

Aside from facilitating the perception and classification of emotions, dynamic displays *support emotion understanding* by inducing external and internal simulation. As an external copy of the observed expression, facial mimicry is typically stronger and more frequent in response to dynamic than static stimuli (Rymarczyk et al., 2011; Sato & Yoshikawa, 2007; Weyers et al., 2006). Furthermore, dynamic expressions allow for an internal representation of the perceived emotion through partial reactivation of sensory, motor, and affective modalities (referred to as embodiment; Niedenthal, 2007). Together, the two may aid intrinsic emotion understanding by activating overlapping mental processes involved in perceiving and experiencing an emotion (Rymarczyk et al., 2016b). This notion is supported by neuroimaging evidence pointing to the recruitment of the mirror neuron system during spontaneous mimicry of dynamic expressions (Rymarczyk et al., 2018, 2019). Such co-activation of brain regions involved in both action execution and observation then contributes to the processing of emotional content (Heyes & Catmur, 2021; Iacoboni, 2009).

In addition, facial mimicry of dynamic expressions serves a social function, *regulating social interactions* in a context-specific manner. Specifically, the imitation of happy and sad expressions is proposed to foster affiliation and emotional communication (such as empathy and rapport), while anger is typically mimicked less due to its non-affiliative nature, instead facilitating threat detection (Fischer & Hess, 2017; Fujimura et al., 2010; Hess & Fischer, 2014; Weyers et al., 2006). Dynamic imitative responses may also facilitate interpersonal coordination and emotional contagion (Chartrand & Lakin, 2013). In this vein, high empathic individuals are found to display more mimicry when expressions are dynamic than static, thereby showing stronger activity in both motor- and emotion-related areas of the mirror neuron system (Rymarczyk et al., 2016b, 2019). Hence, dynamic displays increase the propensity for sharing emotions between sender and perceiver, allowing humans to understand, empathize with and infer others' experiences.

To sum up, moving aspects of facial expressions receive attentional and perceptual priority over static aspects, facilitating their processing both in terms of detection as well as recognition and evaluation. This advantage is likely to enhance the communicative value of facial movements for their social cues (such as understanding the intentions and emotional states of others) and may also underpin interpersonal coordination and empathy.

Multimodal emotion recognition

Facial activity is frequently accompanied by vocalizations, body, hand, head and eye movements, touch and even smells (Darwin, 1872; Keltner & Cordaro, 2017; Keltner, Tracy, Sauter, Cordaro & McNeil, 2016; Scherer & Ellgring, 2007). The need to continuously monitor and detect changes in expression requires the continuous decoding of rapidly changing and partially ambiguous nonverbal and verbal signals pooled across multiple channels (Keltner et al., 2019; FIG. 3). As such, emotion recognition is inherently multi-modal and, unlike identity recognition, so are its deficits with patients unable to recognize emotion from face, voice or body (Young et al., 2020). Dynamic properties of facial expressions including timing, duration and intensity are shared across different channels, enhancing recognition by focusing attention on emotion-relevant attributes (Bahrick et al., 2004; Campanella & Belin, 2007). Other channels add sources of information not present in the face, such as the pitch of the voice and posture of the body, that convey emotion independently and provide potentially complimentary information for emotion recognition (App et al., 2011; Keltner & Cordaro, 2017; Lecker et al., 2020; Mondloch et al., 2013; Young et al., 2020). Multimodal expressions may thus enhance emotion recognition when individual channels are ambiguous in their content and/or performance is not at ceiling levels. In those cases, multisensory integration can be inversely proportional to the effectiveness of the individual stimuli (Klasen, Chen & Mathiak, 2012; Collignon et al, 2008; Stein & Meredith, 1993)

The *voice* is inherently dynamic and tied to facial movement through the mechanics of speech production so that it is possible, for example, to hear someone smiling (Campanella & Belin, 2007; Scherer et al., 2011; Schirmer & Adolphs, 2017; Tartter, 1980). Just as facial movement facilitates, and can even change, speech recognition with distinctions that are difficult to hear like place of articulation (McGurk & MacDonal, 1976; Sumby & Pollack, 1954; Summerfield, 1987), similar facilitative and biasing effects are found for emotion recognition (Aubergé & Cathiard, 2003; De Gelder & Vroomen, 2000; Paulmann & Pell, 2011). Besides the prosody (stress, rhythm, and melody) of speech, emotions are often carried by non-speech sounds like laughing and crying (Juslin & Laukka, 2003; Scherer, 1994). These affect vocalizations, including both non-speech sounds and interjections with phonemic structure (for example “wow”), are better categorised when presented alone than are prosody or facial expression (Banse & Scherer, 1996; Hawk et al., 2009; Schröder, 2003). Interestingly, negative emotions like sadness and fear are well recognised from the voice, while the face is more important for identifying happiness, suggesting complimentary audio and visual information as with speech perception (Hawk et al., 2009; Scherer et al., 2011; Summerfield, 1987). The voice reliably conveys arousal when the mean and variability of pitch and intensity are increased, but the acoustic parameters conveying valence or categorical emotion are less well established and may be better conveyed by the face (Bänziger et al., 2014, 2015; Goudbeek & Scherer, 2010; Juslin & Laukka, 2001; Scherer, 1995; Scherer et al., 2011).

Gaze and head direction modulate expression perception, in part by conveying the expresser's locus of attention (Adams & Kleck, 2005; Hess et al., 2007; Milders et al., 2011; Rigato & Farroni, 2013). In general, there exists a processing advantage for direct (versus averted) gaze of static and moving faces (Bindemann, Burton, Langton, et al., 2008; Krumhuber & Scherer, 2016). Direct gaze also signals approach and facilitates the recognition of approach-oriented emotions such as happiness and anger, whereas averted gaze signals avoidance and facilitates avoidant emotions such sadness and fear (Adams & Kleck, 2003, 2005). In the case of fear, head and gaze angle are further indicative of the direction of a potential threat (Bindemann, Burton, & Langton, 2008; Sander et al., 2007). While static images cue attention, dynamic changes from direct to averted gaze and from a neutral to an expressive face enhance this cuing effect (Dalmaso et al., 2020; Lassalle & Itier, 2015; McCrackin et al., 2019). Finally, head and gaze angle can be expressive in their own right, as when head and eyes signal sadness when lowered but pride when raised (Atkinson et al., 2004; Tracy & Robins, 2004).

Like the face, the *body* conveys emotion via both static configurations and dynamic movement even when the latter are conveyed by point-light displays showing only joint positions (App et al., 2012; Atkinson et al., 2004; Coulson, 2004; Dael et al., 2012; Dittrich et al., 1996; Lecker et al., 2020; Wallbott, 1998a; Witkower & Tracy, 2019). Together, information from the body and face are integrated rapidly and automatically into a new gestalt, with perceptions of an identical facial expression varying as a function of body posture even when the observer is instructed to attend only to the face (Aviezer et al., 2011, 2012; Lecker et al., 2017; Meeren et al., 2005; Mondloch, 2012). In general, facial expression recognition is facilitated by congruent, and disrupted by incongruent body posture, and these effects are greater for dynamic than static displays (Aviezer et al., 2008, 2017; Meeren et al., 2005; Mondloch, 2012; Mondloch et al., 2013; Nelson & Mondloch, 2017). The quality of movement (such as its expansiveness, speed and jerkiness) further varies between emotions and can make emotionally neutral actions like walking and sign language (even for non-signers) expressive (Gross et al., 2010; Hietanen & Leppänen, 2008). While the face may be critical for conveying inner states, the body plays a leading role in indicating motor intention. Additionally, the body helps to differentiate positive expressions and signal social status for emotions like pride and shame (App et al., 2011, 2012; Dael et al., 2012; Mortillaro & Dukes, 2018).

In summary, faces are rarely seen in isolation. Voice, body, and other channels convey emotion themselves and provide a multisensory context that can change, and well as be changed by, how facial expressions are perceived. The demands of emotion recognition benefit from the multimodal pooling of information as this provides complimentary as well as consistent information. The voice is directly and dynamically linked to the face through shared musculature, and this is reflected in emotion as well as speech recognition. Gaze/head direction and body posture further contribute by indicating attention and intention respectively. Combining channels extends the range of recognizable emotions with different channels better at conveying different aspects of what are complex, dynamic, and multimodal patterns of expression.

Summary and Future Directions

Whilst static faces have been crucial in advancing scientific knowledge on emotion recognition, any attempt that ignores the inherently dynamic quality of facial behaviour risks to be incomplete. In this article, we reviewed key evidence showing that facial movement facilitates the ways in which expressions are processed. Besides the added value of spatial/form-related cues, dynamic displays offer distinctive temporal information such as the direction, quality, and speed of movement. All three aspects imply that emotional expressions are manifested in the course of time, with characteristic temporal patterns enhancing the judgement of facial affect when kept in their original, unmodified form. Such recognition advantage points towards the involvement of higher-level cognitive processes. Specifically, facial motion is likely to be part of rich internal (mental) representations that engage complex networks of brain areas (including the posterior superior temporal sulcus) and guide a range of social and emotional inferences. The positive influence is most evident in suboptimal conditions when observers are impaired and/or facial expressions are degraded or subtle. Due to their evolutionary significance dynamic face representations recruit early attentional and motivational resources in the perceiver, facilitating the prompt detection and prediction of others' emotional states. Furthermore, they support emotion understanding through simulation processes and regulate social interactions by inducing emotional contagion.

In the future it will be important to consider expressive displays in their unique dynamic quality as sequential patterns of facial actions that unfold over time (Jack & Schyns, 2015; Krumhuber & Scherer, 2011), and not merely as static-based representations with movement added on. There has been a widespread assumption that moving stimuli are ecologically valid by themselves. This claim may not necessarily hold when considering the many ways in which movement can be operationalized. Until now, many studies still rely on image morphing techniques to create a moving display (Dawel et al., 2021). Such an approach does not capture the idiosyncratic nature of facial movements, potentially failing to represent the true form of dynamic expressions. Seeing a face move adds both static- and dynamic-based information (Lander & Bruce, 2000). An important step to be undertaken is to investigate the relative contribution of each source to emotion perception and unravel the mechanisms underpinning the dynamic advantage. To that end, more micro-analytical studies are needed regarding the spatio-temporal aspects of facial displays (Sowden et al., 2021). While manual coding techniques used in the past were less detailed and precise, the emergence of technology within the field of affective computing allows for the quantification of dynamic facial behaviour (Küster et al., 2020)

With computer-assisted analysis tools, future research could move beyond highly controlled face stimuli simulated or posed by actors. 89% of studies to date still employ deliberately posed expressions that have been manipulated or selected (often dragged arbitrarily from a video sequence and/or from the vertex of the whole development) to achieve high accuracy in emotion recognition (Dawel et al., 2021). This issue is especially pertinent with respect to questions about the affective realism and authenticity of expressions (Zloteanu & Krumhuber, 2021; Krumhuber, Skora, Küster, & Fou, 2017). Emotion classification proves to be more difficult with spontaneous (than posed) stimuli (Krumhuber et al., 2021a, 2021b), partly because spontaneous (similar to real-life) expressions are more subtle, ambiguous, and heterogenous in their facial action patterns (Calvo & Nummenmaa, 2016). Failing to accept this natural variability not only curtails progress in capturing the full repertoire of facial behaviour, but limits insights into the mechanisms that drive human emotion processing. In the future there is a strong need to study to a greater extent spontaneous expressions that are deliberately uncontrolled, including naturalistic stimuli that closely resemble those 'in the wild' (Fernández-Dols, 2017; Mollahosseini, Hasani, & Mahoor, 2016; Srinivasan & Martinez, 2021). By doing so, critical information is to be revealed about facial features and their role in emotion perception.

The idiosyncratic and individualistic nature of real-world expressions is also a defining feature for identity recognition. Not surprisingly, facial motion contains both expression- and identity-specific information (BOX 1), which on an everyday basis are processed simultaneously (Lander & Chuang, 2005). What is the shared importance of dynamic information across these two types of face processing? Seeing a face move in particular ways can provide relevant clues regarding the person's identity. Conversely, familiarity with a person may affect how emotionally intense or genuine an expression appears to be (Lander & Butcher, 2020). The interdependence between expression recognition, motion and face familiarity demands future attention, with novel insights to be gained into how emotion perception abilities vary among healthy and clinical populations (Lander et al., 2007). Another issue that requires more consideration is the multi-modal nature of dynamic expressions. As patterns of facial actions commonly appear alongside other verbal and nonverbal cues, they should be considered together (Partan & Marler, 1999).

Besides greater stimulus diversification, further research might be aimed at expanding the repertoire of emotions being studied, spanning a large range of emotional states apart from the basic six (Benda & Scherf, 2020; Cowen et al., 2021). Less is still known about how dynamic information is encoded in non-basic affective states such as frustration, boredom, and interest (Zeng et al., 2009). Which motion properties are associated with each emotion? How are they represented in the human face perception system? While lots of advancements have been made in building models on static face perception (with high predictivity in the occipital/fusiform face area), there is a lack of neural encoding models for processing dynamic faces (Grill-Spektor et al., 2017; Bernstein, Erez, Blank & Yovel, 2018). Given that expression recognition is inherently a dynamic process, the brain constantly integrates sensory (dynamic and static) cues based on their respective reliabilities to achieve robust perception (Haxby et al., 2000). Important novel questions pertain to the functional architecture and connectivity of brain networks. What are the computations and connectivity patterns involved in dynamic expression perception? How do they interact with other brain areas outside the core face-selective regions to support broader socio-cognitive processing? The role of deep neural networks and deep learning might be an especially interesting avenue to explore (Grill-Spektor et al., 2017). Elucidating relevant computations and interrelationships not only results in better predictions of human behaviour but provides a richer understanding of the underlying mechanisms (Grill-Spektor et al., 2017; Pitcher & Ungeleider, 2021). The present article discussed evidence as to what dynamic displays offer in comparison to static images and when, how, and why this information matters. We hope it proves useful for advancing existing knowledge regarding the role of facial movement in emotion recognition.

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Competing interests

The authors declare no competing interests.

Table 1 / **Experimental techniques for studying the role of facial movements in emotion recognition.**

	Description	Effects	Key References
Noise masks	Adding a visual noise mask between static images to interrupt the apparent motion whilst maintaining the amount of static-based content. ‘Multi-static’ sequences are formed.	Accuracy is significantly reduced for multi-static compared to dynamic sequences, demonstrating that the perceived movement is the critical aspect of dynamic displays (rather than just static-based information).	Ambadar et al., 2005; Bould & Morris, 2008; Krumhuber & Manstead, 2009
Random frame order	Altering the order of the frames within a dynamic sequence, distorting the natural temporal sequence of the observed motion.	Recognition performance significantly decreases as the natural sequence of the motion is disrupted. In some cases, recognition is better for single static images compared to random order sequences.	Cunningham & Wallraven, 2009b; Furl et al., 2010; Schultz et al., 2013; Plouffe-Demers et al., 2019
Unpredictable or disrupted rhythm	Altering the rhythm of the observed dynamic sequence by decreasing the number of frames or changing the relative timing of frames shown.	The flow of motion is disrupted, with motion typically appearing more ‘jerky’. Recognition performance is adversely affected.	Bould, Morris, & Wink, 2008; Perdikis et al., 2017
Timeline reversal	Reversing the temporal order of the frames in the sequence by playing them in a backwards order.	Backwards motion leads to atypical facial motion trajectories, reducing accurate emotion recognition.	Delis et al., 2016; Korolkova, 2018; Reinl & Bartels, 2015; Sato, Kochiyama & Yoshikawa, 2010
Linear morphing	Gradually morphing between two images (usually neutral and expression apex) creates a dynamic emotion that smoothly and linearly moves.	Morphing removes natural characteristics of motion and negatively impacts the perception of the viewed expression.	Dobs et al., 2014; Wallraven et al., 2008; Cosker et al., 2010.

Changing speed	Changing the velocity of facial expressions by increasing or decreasing the frame rate or timing of the observed motion.	Effect varies between emotions based on their intrinsic velocities. For example, sadness is the slowest emotion and its recognition is enhanced by slowing. Speeding up facial expressions promotes anger and happiness judgments.	Kamachi et al., 2001; Pollick et al., 2003; Recio, Schacht, & Sommer, 2013 Sowden et al., 2021

Table 2 / **Conditions that facilitate the dynamic advantage**

Source	Aspect	Instances	Key References
Stimulus	Facial form is degraded in shape or texture; reduced realism or resolution	Low pass filtering, inversion, misalignment, masking, point-light displays, line drawings, artificial faces	Ehrlich et al., 2000; Kätsyri & & Sams, 2008; Atkinson et al., 2012; Tobin et al., 2016; Wallraven et al., 2008
Stimulus	Expressed emotion is difficult to discern	Weak intensity, non-basic emotion, ambiguous, blended expression	Ambadar et al., 2005; Bould & Morris, 2008; Hess & Kleck, 1990; Yitzhak et al., 2018
Context	Viewing condition is constrained or problematic	Peripheral presentation	Sato et al., 2014; Kouider et al., 2013
Observer	Recognition ability is impaired	Prosopagnosia, dementia, autism, schizophrenia, old age, brain injury, Parkinson's disease, depression	Gepner et al., 2001; Adolphs et al., 2003; Ziaei et al., 2021; Garrido-Vasquez et al., 2011

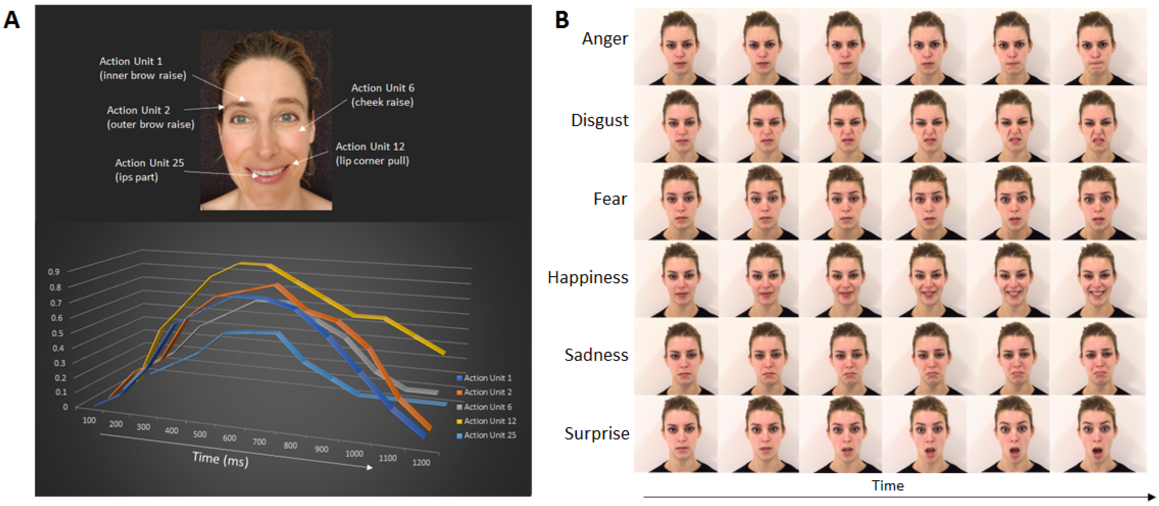

Fig 1. / **Temporal trajectory of facial actions.** Facial expressions evolve in a dynamic fashion, transmitting patterns of signals over time. Those can be analysed in terms of temporal and kinematic features such as displacement, velocity, and acceleration (A). Temporal progression of facial expressions for the six basic emotions from onset to apex (B). Images adapted with permission from the Amsterdam Dynamic Facial Expression Set (Van der Schalk, J., Hawk, S. T., Fischer, A. H., & Doosje, B. (2011). Moving faces, looking places: Validation of the Amsterdam Dynamic Facial Expression Set (ADFES). *Emotion, 11,* 907–920).

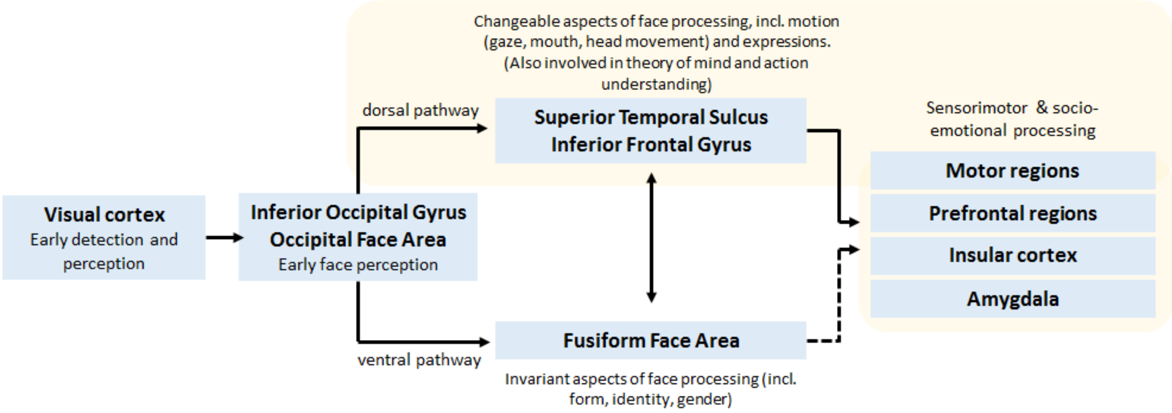

Fig. 2 / **Schematic of the standard neural model of face perception.** Early detection and perception are subserved by early visual cortex and the occipital regions, which provide input to the ventral pathway, predominantly the fusiform face area (concerned with largely invariant features of faces) and the dorsal pathway, predominantly the posterior superior temporal sulcus and the inferior frontal gyrus (concerned with changeable features). Activity in the shaded regions is enhanced in response to viewing dynamic, compared to static, facial expressions. Dynamic expressions also provoke stronger and more widespread activation of the non-face-specific regions involved with sensorimotor and socio-emotional processing, compared to static expressions (dashed line). Adapted from Haxby et al (2000), O'Toole et al (2002), Bernstein et al (2018).

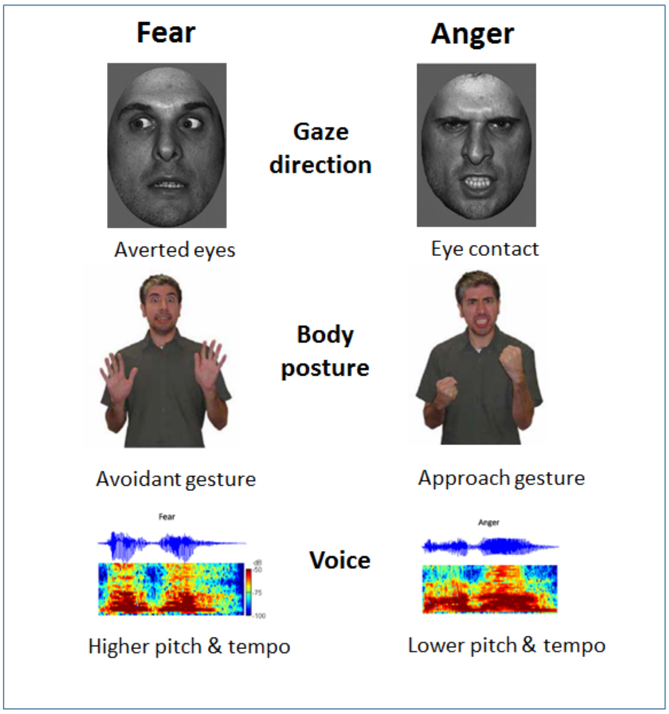

Fig. 3 / **Multiple channels of information, as illustrated on the basis of fear and anger.** Gaze direction modulates perceived expression in particular by cuing locus of attention. Body posture conveys emotion and modulates perceived expression by indicating motor intention (approach vs avoidance). Vocal properties (e.g., pitch and tempo) effectively convey emotion, are tied to facial expression through the mechanics of production and convey arousal. Shared properties across channels like timing and intensity provide redundancy and facilitate recognition, while channel-specific properties are disambiguating and best suited to convey different dimensions of emotion.

Box 1 / Key theoretical frameworks on the interaction between face identity and expression recognition

Model	Description	Points for consideration
Bruce & Young (1986)	Cognitive model that proposes that identity and expression recognition are carried out independently but in parallel.	There is some evidence for independence (Tranel, Damasio & Damasio, 1988; Young et al., 1986), but other work suggests that emotional aspects of a target face modulate the process of identification (Schweinberger & Soukup, 1998; Wang et al.,2013) No consideration of dynamic aspects of faces.
Haxby, Hoffman & Gobbini (2000)	Neural model that proposes that changeable (expressions) and invariant (identity) aspects of faces are processed via dissociable cortical pathways.	Evidence supports the involvement of occipital face area (OFA) and fusiform face area (FFA) in the recognition of identity, and the involvement of posterior superior temporal sulcus (pSTS) in the recognition of expressions (Hoffman & Haxby, 2000; Kanwisher et al. 1997). However, the recognition of face identity and facial expressions might be more integrated than originally proposed (Dobs et al., 2018; Ganel, Valyear et al., 2005 Kliemann et al., 2018). Dynamic motor and static components of a face are thought to be processed via dissociable cortical pathways (Pitcher et al., 2014).
O'Toole, Roark & Abdi (2002)	Theoretical account to explain why facial movement may enhance face recognition. Movement of the face often involves expressive movements.	'Supplemental Information Hypothesis' proposes that we represent characteristic facial motions (for example, a wry smile) of individual faces in addition to the invariant structure of the face. 'Representation Enhancement Hypothesis' proposes that facial motion contributes to recognition by facilitating perception of the three-dimensional structure of a face. Accounts are not specific to expression type or the relationship between identity and expression recognition.
Rhodes et al. (2015)	Proposal that there are common dimensions in perceptual face space that code both identity and expression.	Research using visual aftereffects suggests that visual coding of face identity and expression is not completely distinct. Adaptation of those common dimensions predicts recognition of both attributes. It challenges the traditional 'independent' view of identity and expression recognition processing but is based on static images.