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Illusory feature slowing: Evidence for perceptual models of global facial change

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Abstract

Upright static faces are widely thought to recruit holistic representations, whereby individual features are integrated into non-decomposable wholes for recognition and interpretation. In contrast, little is known about the perceptual integration of dynamic features when viewing moving faces. We are frequently exposed to correlated eye and mouth movements such as the characteristic changes accompanying facial emotion, yawning, sneezing and laughter. However, it is unclear whether the visual system is sensitive to these dynamic regularities, encoding facial behavior relative to a set of dynamic global prototypes, or whether it simply forms piecemeal descriptions of feature states over time. To address this question, we sought evidence of perceptual interactions between facial features. Crucially, we find illusory slowing of feature motion in the presence of another moving feature, limited to upright faces and particular relative-phase relationships. Perceptual interactions between dynamic features suggest that local changes are integrated into models of global facial change.

Key words: facial motion, phase, blinking, velocity, orientation, avatar

Introduction

Upright static faces are thought to be perceived holistically, whereby features are grouped into configurations. The composite face illusion provides striking evidence for holistic representation. When a region from one face is replaced by the corresponding region from another, perception of the unaltered region is radically distorted; for example, perceptual fusion of the unaltered and transplanted regions alters the perceived identity (Young, Hellawell, & Hay, 1987), expression (Calder, Young, Keane, & Dean, 2000) and attractiveness (Abbas & Duchaine, 2008) of the unaltered region. Further evidence for holistic representation comes from the part-whole effect, whereby individual features are easier to discriminate when embedded within facial contexts, despite the context being uninformative (Tanaka & Farah, 1993). Importantly, these hallmarks of holistic representation are greatly reduced when faces are viewed upside down (Susilo, Rezlescu, & Duchaine, 2013). Because basic stimulus properties are preserved by orientation inversion, upright and upside-down faces should engage generic feature-binding operations equally. Inversion effects therefore indicate that feature integration is mediated by mechanisms tuned to upright faces. Holistic representation is not inconsequential, it is thought to be causally related to face recognition ability, permitting accurate, efficient interpretation (Avidan, Tanzer, & Behrmann, 2011; Gauthier, Klaiman, & Schultz, 2009).

While face perception has traditionally been studied using static images, the faces we encounter in our daily lives are dynamic (O'Toole, Roark, & Abdi, 2002). Facial motion signatures – characteristic patterns of movement – support identity and gender recognition (Cook, Johnston, & Heyes, 2012; Hill & Johnston, 2001; Knight & Johnston, 1997; Lander, Christie, & Bruce, 1999) and certain face-selective brain regions, notably the superior temporal sulcus, respond disproportionately to moving faces (Pitcher, Dilks, Saxe, Triantafyllou, & Kanwisher, 2011; Polosecki et al., 2013). Despite the significance of facial motion, relatively little is known about the perceptual representation of moving faces. In particular, nothing is known about the hierarchical binding of dynamic feature states, whether the perception of moving faces also benefits from holistic processing. Dynamic facial expressions are known to comprise correlated feature changes (Jack, Garrod, & Schyns, 2014), co-variation that may determine the grouping of facial features into configurations (Johnston, 2011). However it remains unclear whether the visual system is sensitive to these dynamic regularities, encoding facial behavior relative to a set of dynamic global expression prototypes, or whether it simply forms a piecemeal description of feature states over time.

To determine whether dynamic feature states are integrated into global representations of facial change, we sought evidence of perceptual interactions between dynamic facial features. This approach is directly comparable with the composite face illusion (Abbas & Duchaine, 2008; Calder et al., 2000; Young et al., 1987), perhaps the best evidence that static faces recruit holistic representations, whereby perceptual integration of eye and mouth regions impairs recognition of the different source faces. Should local feature dynamics be integrated into a representation of global facial change, the presence of a task-irrelevant dynamic feature might be expected to alter perception of a task-relevant dynamic feature. We describe a new dynamic-face illusion suggestive of feature integration processes that are orientation-specific and sensitive to the relative-phase relationships of feature change.

General methods

On each trial, participants viewed two avatar faces side-by-side. Both faces opened and closed their eyes periodically at 1.25 Hz. Participants were asked to report whether the speed of eyelid motion was greater for the standard or comparison. Participants were free to fixate each face in turn. Concurrent mouth-opening and -closing movements were presented on the standard, also at 1.25 Hz. The eyelid transitions, open-to-closed and *vice versa*, exhibited by the standard stimulus always lasted 140 ms. The mouth on the comparison stimulus remained closed throughout. Eyelid transitions for the comparison stimulus varied in duration from 20 ms (rapid transition) to 260 ms (slow transition) in steps of 40 ms. Orientation was manipulated by presenting the standard upright or inverted; the comparison stimulus was always presented upright. Whether the standard appeared on the right or left was counter-balanced. Trial type was interleaved within mini-blocks of 70 trials. Participants always completed 280 trials (7 comparison durations × 2 orientations × 20 presentations).

The perceived speed of the standard eyelid transition was inferred from the point of subjective equality (PSE) on the resulting psychometric function; an estimate of the comparison transition necessary for the comparison and standard to be judged equivalent. Psychometric functions were estimated by fitting cumulative Gaussian functions in Matlab using the Palamedes toolbox (Prins & Kingdom, 2009).

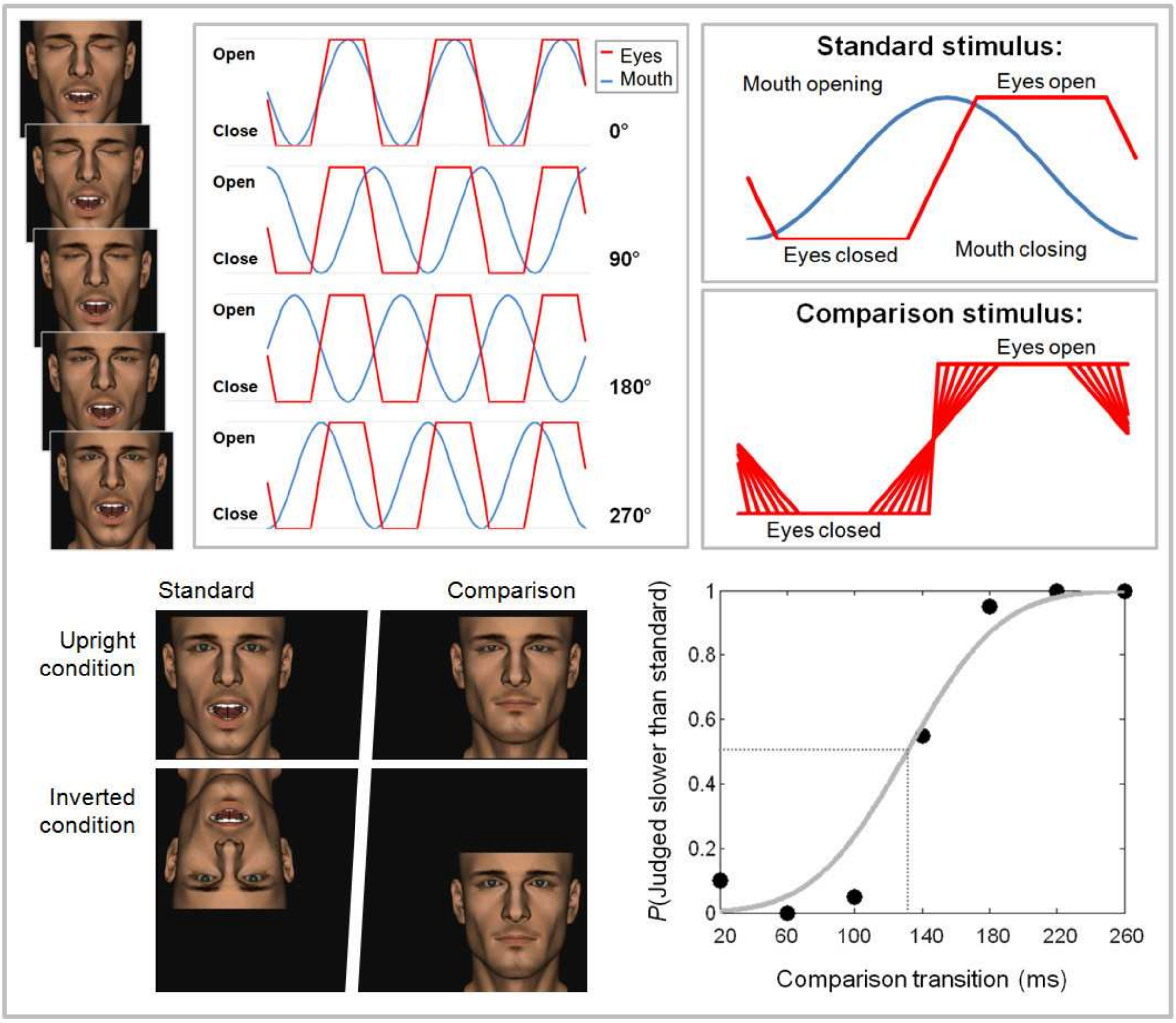

Figure 1: Illustration of the frame sequences used to create the stimuli (top left). Schematic illustration of the eye and mouth transitions presented on the standard stimuli in the different phase conditions (top-middle). Schematic illustration of the eye and mouth transitions presented in the 270° standard stimulus and the seven comparison stimuli (top-right). Trials presented the standard and a comparison stimulus simultaneously and required observers to judge which blinked faster (bottom-left). The perceived velocity of the standard was inferred by estimating the comparison transition judged equivalent (bottom-right).

Stimulus frames were created by posing the eyes and mouth of an avatar face in Poser 7 (e frontier America, Inc). Frames were saved as bitmaps and compiled into uncompressed audio-visual-interleave (.avi) files using Matlab (The MathWorks, Inc). Each stimulus comprised 40 frames saved and presented at 50 frames per second (fps). Each avatar stimulus subtended 8° vertically when viewed at 60 cm. During the experiment, stimuli completed 8 cycles, presented on CRT monitors at a refresh rate of 85 Hz. Experimental programs were written in Matlab with Psychtoolbox (Brainard, 1997; Pelli, 1997).

Experiment 1

Our first experiment sought to determine whether the perceived speed of blinking movements is altered by the presence of concurrent mouth opening and closing. We measured the perceived speed of eyelid movements, in both upright and inverted faces, at four relative-phase relationships (Figure 1). If dynamic features are integrated into configurations via a face-specific mechanism, concurrent mouth movements might be expected to bias perception of eyelid motion disproportionately when faces are viewed upright. Thirty-two neurotypical observers (mean age = 25.8 years, 20 males) with normal or corrected-to-normal vision participated in Experiment 1. Sample size was determined a priori, informed by previous psychophysical investigations of demonstrable visual illusions. Participants were randomly allocated to one of the four phase conditions in equal numbers. Phase comparisons were made between-subjects to limit adaptation to the manipulation.

ANOVA with orientation as a within-subjects factor, and phase as a between-subjects factor, revealed a significant main effect of orientation [$F(1,28) = 23.129$; $p < .001$, $\eta^2 = .452$] and a significant phase × orientation interaction [$F(1,28) = 4.510$; $p = .011$, $\eta^2 = .326$]. When presented upright, the presence of the mouth movements caused the eyelid transitions to be perceived as slower (M = 164 ms, SD = 19 ms) than the veridical duration of 140 ms [$t(31) = 7.167$; $p < .001$] and slower than the inverted transitions (M = 150 ms, SD = 14 ms) [$t(31) = 4.155$; $p < .001$]. Disproportionate illusory slowing of the eyelid movements was seen at two phase relationships when the standard appeared upright (Figure

2). The effect was most pronounced at the 270° phase relationship, where the standard was judged slower [$t(7) = 5.159$; $p = .001$] when presented upright ($M = 178$ ms, $SD = 27$ ms) than when inverted ($M = 148$ ms, $SD = 17$ ms). Similar effects were also seen at 180°, where the standard was again perceived as slower [$t(7) = 2.939$; $p = .022$] when viewed upright ($M = 166$ ms, $SD = 16$ ms), relative to inverted presentation ($M = 147$ ms, $SD = 9$ ms).

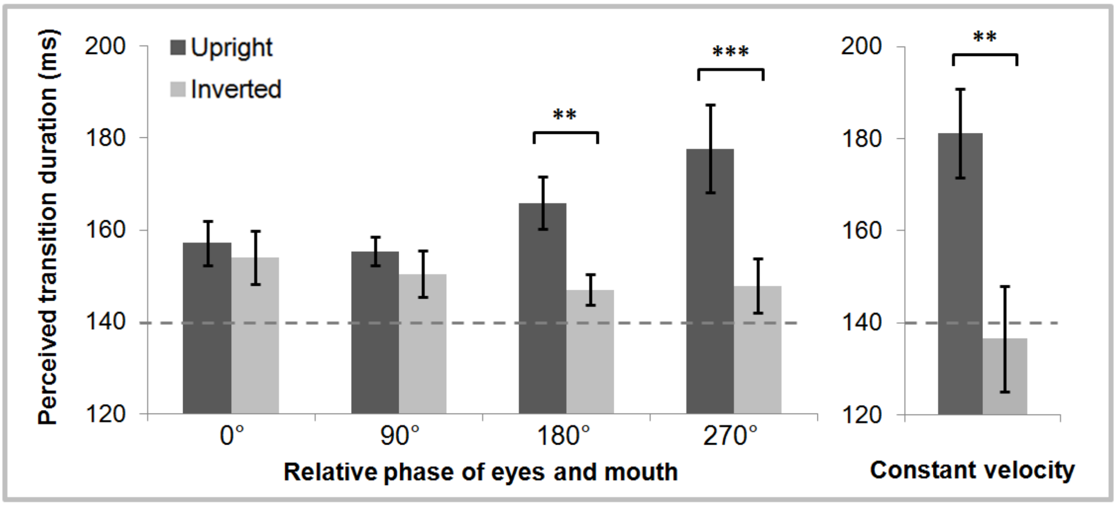

Figure 2: Results from Experiment 1 (left). When paired with concurrent mouth movements the standard eye-blinking transition appeared slower when viewed upright than viewed upside down. The effect was most pronounced at the 270° phase relationship, although similar effects were also seen at 180°. Results from Experiment 2 (right). Illusory slowing of the eyelids was seen at 270° irrespective of whether the bottom jaw was animated with a sinusoidal or constant velocity kinematic profile. Dashed lines indicate the veridical transition duration. Error bars indicate ±1 *SEM*. *$p < .05$; **$p < .025$; ***$p < .001$.

Experiment 2

Our second experiment sought to determine whether the illusory slowing was a product of the different kinematic profiles of the eye and mouth movements. In Experiment 1, the mouth movements exhibited by the standard were created by animating the bottom jaw of the avatar with a sinusoidal velocity profile whereas the eye-blinking movements followed a constant velocity profile. It is possible that the illusory slowing observed is caused by these different feature dynamics. For example, the presence of sinusoidal mouth movements may create the expectation that the eyelids will also move with a sinusoidal profile. To determine whether the different velocity profiles were responsible for the illusory slowing, we replicated the 270° phase condition with constant-velocity mouth movements. A further eight neurotypical observers (mean age = 29.1 years, 3 males) with normal or corrected-to-normal vision completed Experiment 2.

The standard transition was again judged slower when presented upright (*M* = 181 ms, *SD* = 27 ms; Figure 2) than when presented inverted (*M* = 137 ms, *SD* = 32 ms) [$t(7) = 3.058$; $p = .018$]. When viewed upright the perceived duration of the standard was also significantly slower than its physical duration of 140 ms [$t(7) = 4.295$; $p = .004$]. That illusory slowing of the constant velocity eyelid transitions is produced by both sinusoidal and constant velocity mouth movements confirms that the different kinematic profiles are not responsible for the effect.

Discussion

The illusory slowing observed is suggestive of cross-feature perceptual interactions, whereby dynamic mouth and eye states are integrated into perceptual models describing global facial change. It appears we not only represent the states of disparate features at a given point in time holistically, but also how coordinated facial changes unfold over time. That feature slowing is not observed for inverted faces indicates that integration of feature dynamics is mediated by a face-specific modeling process, and does not reflect lower-level attribute binding. The phase-dependence of these effects suggests that internal models of global facial change have preferred phases, and that features with different dynamics are attracted to these models. Feature slowing appears to reflect phase adjustment of feature dynamics, whereby change is delayed to match the global models. We speculate that perceptual models of global facial change emerge following visual exposure to reliable contingencies between dynamic feature changes and that similar effects may be observed for other types of correlated facial change.

The illusory slowing observed is conceptually similar to the composite face illusion described with static faces, where the presence of a task irrelevant feature – in this case the opening and closing mouth – distorts perception of a task-relevant feature – the speed of eyelid transitions. Strikingly, observers' judgments of the task-relevant feature were more accurate when the avatar faces were viewed upside-down. Because configural interference is seen only when concurrent mouth movements appear on an upright face, judgments of eyelid speed were more accurate – closer to the veridical – when faces were viewed upside-down. Reduced integration of feature dynamics in the inverted orientation may explain why facial motion signatures are harder to recognize when viewed upside-down (Cook et al., 2012; Hill & Johnston, 2001; Knight & Johnston, 1997; Lander et al., 1999).

Illusions reveal underlying perceptual processes by presenting the visual system with input that departs from that encountered outside the laboratory. For example, by violating expectations about room shape the 'Ames Room' illusion, where actors appear tiny or enormous depending on where they stand within a specially constructed room (Ames, 1952), reveals how prior expectations about depth and shape influence our perception of size. Similarly, the composite face illusion (Young et al., 1987) reveals processes of holistic representation, thought to be routinely recruited by naturalistic faces, using contrived facial images created using top and bottom face halves from different identities. Following the same logic, the motion of our avatars is not intended to appear naturalistic and may seem quite unusual. Crucially however, understanding how these stimuli deceive the visual system may help to reveal how naturally occurring facial motion is represented.

Overall, the experiments described here contribute much needed insight into the operation of hierarchical mechanisms responsible for integrating local feature dynamics and the holistic processes recruited by moving faces. Perceptual interactions between facial features reveal face-specific encoding mechanisms that integrate dynamic features into expression prototypes, encompassing global properties of facial change.

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Author contributions

RC and AJ contributed equally to the design of all experiments and drafted the manuscript for publication. RC constructed the stimuli and wrote the experimental program. RC and CA collected and analyzed the data.

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Supplementary movie captions

Supplementary Movie 1:

When viewed upright, concurrent mouth movements at a relative-phase of 270° produce illusory slowing of the eyelid transitions. Veridical perception of the eyelid transitions is easier in the absence of the mouth movements. The illusory slowing disappears when the stimulus is inverted (see Supplementary Movie 2).

Supplementary Movie 2

When viewed upside down, concurrent mouth movements at a relative-phase of 270° produce little or no illusory slowing of the eyelid transitions.