Psychological Science OnlineFirst, published on February 23, 2015 as doi:10.1177/0956797614567340

Research Report

Psychological Science
1–6

DOI: 10.1177/0956797614567340
pss.sagepub.com

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 nondecomposable wholes for recognition and interpretation. In contrast, little is known about the perceptual integration of dynamic features when viewing moving faces. People are frequently exposed to correlated eye and mouth movements, such as the characteristic changes that accompany 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 dynamic facial features. Crucially, we found illusory slowing of feature motion in the presence of another moving feature, but it was 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.

Keywords

facial motion, phase, velocity, orientation, avatar

Received 7/29/14; Revision accepted 12/16/14

Observers are thought to perceive upright static faces holistically, grouping individual features into configurations. The composite-face illusion provides striking evidence for holistic representation of faces: When a region from one face is replaced with 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 a facial context, despite the context being uninformative (Tanaka & Farah, 1993). Hallmarks of holistic representation are greatly reduced when faces are viewed upside down (Susilo, Rezlescu, & Duchaine, 2013). Because basic stimulus properties are preserved during inversion, upright and inverted faces should equally engage generic feature-binding operations. Inversion effects therefore indicate that feature integration is mediated by mechanisms tuned to upright faces.

Although face perception has traditionally been studied using static images, the faces people encounter in their 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

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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 its perceptual representation. In particular, nothing is known about the hierarchical binding of dynamic feature states. Dynamic facial expressions are known to comprise correlated feature changes (Jack, Garrod, & Schyns, 2014)—covariation 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 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 paradigm (Abbas & Duchaine, 2008; Calder et al., 2000; Young et al., 1987), which has been widely used to demonstrate perceptual integration of eye and mouth regions in static faces. If local feature dynamics are 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 that suggests the existence of feature-integration processes that are orientation-specific and sensitive to the relative phase relationships of feature change.

General Method

On each trial, participants viewed, side by side, two avatar faces that appeared to open and close their eyes periodically. On both face stimuli, the eyes opened and closed at a frequency of 1.25 Hz. On the standard face only, the mouth opened and closed as well, also at a frequency of 1.25 Hz; on the comparison face, the mouth remained closed throughout (see the movies in the Supplemental Material available online). An eyelid transition (i.e., from open to closed or vice versa) on the standard face always lasted 140 ms; eyelid transitions on the comparison face varied in duration from 20 ms (rapid transition) to 260 ms (slow transition) in steps of 40 ms. Orientation was manipulated by inverting the standard face; the comparison face was always presented upright (Fig. 1d). Whether the standard face appeared on the right or left was counterbalanced. Participants were asked to report whether the speed of eyelid motion was greater for the standard face or for the comparison face. Participants were free to fixate each face in turn. Trial types were interleaved within miniblocks of 70 trials. Participants always completed 280 trials in total (7 comparison durations × 2 orientations × 20 presentations).

The perceived speed of the standard eyelid transition was inferred from the point of subjective equality on the resulting psychometric function (Fig. 1e)—an estimate of the transition duration necessary for the comparison face to be judged equivalent to the standard face. Psychometric functions were estimated by fitting cumulative Gaussian functions in MATLAB (Version 2013b; The MathWorks, Natick, MA) using the Palamedes toolbox (Prins & Kingdom, 2009).

Stimulus frames were created by posing the eyes and mouth of an avatar face in Poser (Version 7; e frontier America, Scotts Valley, CA). Frames were saved as bitmapped graphics and compiled into uncompressed audio-visual-interleave (.avi) files using MATLAB. Each stimulus was composed of 40 frames and was presented at 50 frames per second (Fig. 1a). Each avatar stimulus subtended 8° of vertical visual arc when viewed at 60 cm. Stimuli completed eight cycles and were presented on CRT monitors at a refresh rate of 85 Hz. Experimental programs were written in MATLAB with Psychophysics Toolbox (Brainard, 1997; Pelli, 1997).

Experiment 1

We sought to determine whether the perceived speed of eyelid motion was altered by the presence of concurrent mouth opening and closing. We measured the perceived speed of eyelid movements, in both upright and inverted faces, in four phase conditions (Figs. 1b and 1c): mouth and eyes closing in phase, 0°; eyes close before mouth closes, 90°; mouth and eyes closing out of phase, 180°; and mouth closes before eyes close, 270°. 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 the four phase conditions in equal numbers. Phase comparisons were made between subjects to limit adaptation to the manipulation.

Analysis of variance 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 the stimuli were presented upright, the presence of the mouth movements caused the eyelid transitions to be perceived as slower ($M = 164$ ms, $SD = 19$ ms)

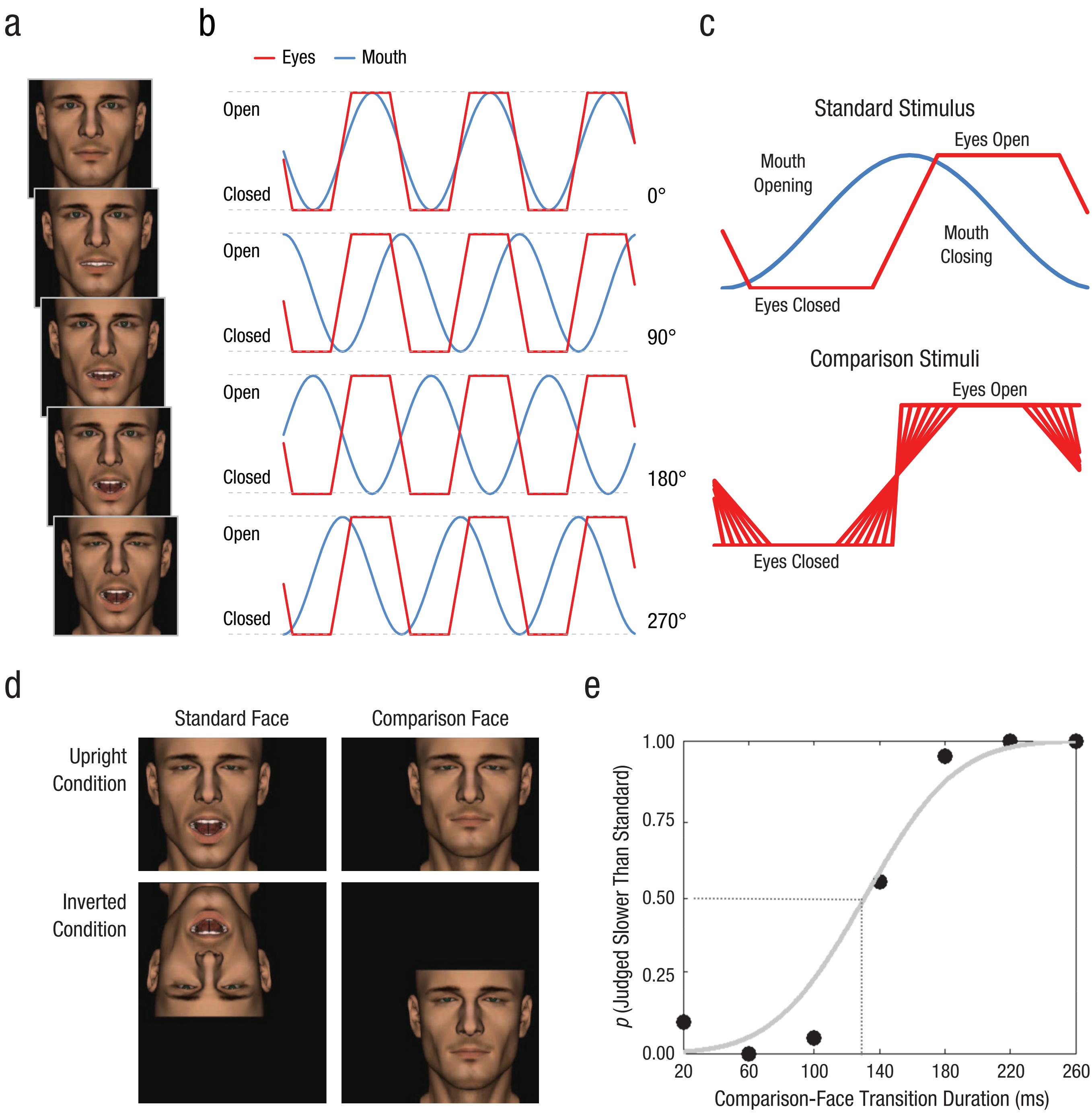

Fig. 1. Creation of the stimuli and experimental design. The illustration in (a) shows a sequence of 5 of the 40 frames used to create the stimuli. The schematic illustration in (b) shows the relative eye and mouth transitions presented on the standard stimulus in the different phase conditions. The schematic illustration in (c) compares the eye and mouth transitions presented on the standard stimulus in the 270° phase condition and the seven comparison stimuli, which had different transition speeds. Trials presented a standard stimulus and a comparison stimulus simultaneously (d). The standard stimulus was either upright or inverted; in the inverted condition, the faces were adjusted so that the eyes were aligned horizontally. Observers were required to judge which face exhibited faster eyelid motion. The perceived velocity of the eyelid transition on the standard face was inferred by estimating the transition duration necessary for the comparison face to be judged equivalent, as shown in (e).

than the veridical duration of 140 ms, $t(31) = 7.167$, $p < .001$, and slower than the inverted transitions ($M = 150$ ms, $SD = 14$), $t(31) = 4.155$, $p < .001$. Disproportionate illusory slowing of the eyelid movements was seen in two phase conditions when the standard appeared upright (Fig. 2). The effect was most pronounced in the

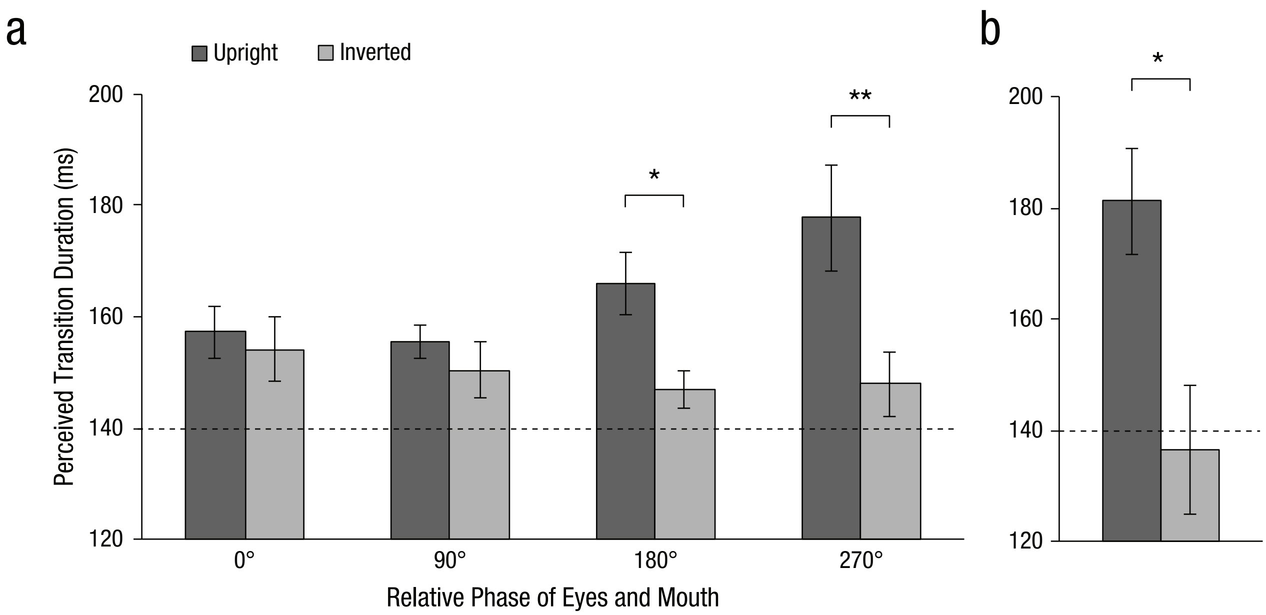

Fig. 2. Results from (a) Experiment 1 and (b) Experiment 2: perceived duration of eyelid transitions in the upright and inverted conditions. For Experiment 1, perceived transition duration is shown separately for each of the phase conditions. In Experiment 2, perceived transition durations were estimated for the 270° phase condition only. The dashed lines indicate the veridical transition duration. Error bars represent ±1 *SEM*. Asterisks denote significant differences in perceived duration of eyelid transitions in the upright and inverted conditions (* $p < .025$, ** $p < .001$).

270° phase condition; the standard was judged to be slower when presented upright (M = 178 ms, SD = 27) than when inverted (M = 148 ms, SD = 17), $t(7) = 5.159$, $p = .001$. Similar effects were also seen in the 180° phase condition; the standard was again perceived as slower when the stimuli were upright (M = 166 ms, SD = 16) than when they were inverted (M = 147 ms, SD = 9), $t(7) = 2.939$, $p = .022$.

Experiment 2

In our second experiment, we 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 eyelid motion followed a constant-velocity profile. It is possible that the illusory slowing observed was caused by these different feature dynamics. For example, the presence of sinusoidal mouth movements may have created the expectation that the eyelids would 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. Eight new 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 to be slower when presented upright (M = 181 ms, SD = 27; Fig. 2) than when presented inverted (M = 137 ms, SD = 32), $t(7) = 3.058$, $p = .018$. The perceived duration of the upright standard face was also significantly slower than its physical duration of 140 ms, $t(7) = 4.295$, $p = .004$. Our findings that illusory slowing of the constant-velocity eyelid transitions is produced by both sinusoidal- and constant-velocity mouth movements confirm 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 that people represent not only the states of disparate features at a given point in time holistically, but also how coordinated facial changes unfold over time. Feature slowing is not observed for inverted faces, which indicates that integration of feature dynamics is mediated by a face-specific modeling process rather than lower-level attribute binding. The phase dependence of these effects suggests that internal models of global facial change have preferred phases, and that dynamic features with different phase relationships 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 presented here is conceptually similar to the composite-face illusion described with static faces; 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 inverted. Because configural interference was stronger when concurrent mouth movements appeared on an upright face, judgments of eyelid speed were more accurate—estimates of the standard transition were closer to the veridical duration—when faces were inverted. Reduced integration of feature dynamics in the inverted orientation may explain why facial motion signatures are harder to recognize when they are inverted (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, in which 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. Likewise, in the composite-face illusion (Young et al., 1987), processes of holistic representation thought to be routinely recruited by naturalistic faces are revealed using contrived images that combine top and bottom halves of faces from different identities. Likewise, the motion of our avatars is not intended to appear naturalistic. However, understanding how these stimuli deceive the visual system may reveal how naturally occurring facial motion is represented.

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.

Author Contributions

R. Cook and A. Johnston contributed equally to the design of all experiments and drafted the manuscript for publication. R. Cook constructed the stimuli and wrote the experimental program. R. Cook and C. Aichelburg collected and analyzed the data.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Funding

This work was supported by Economic and Social Research Council Future Research Leaders Grant ES/K008226/1 (to R. Cook), Engineering and Physical Sciences Research Council Research Project Grant EP/F037503/1 (to A. Johnston), Leverhulme Trust Fellowship RF-2013-037 (to A. Johnston), and Leverhulme Trust Research Project Grant RPG-2013-218 (to A. Johnston).

Supplemental Material

Additional supporting information can be found at http://pss.sagepub.com/content/by/supplemental-data

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