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The Effect of Side-to-Side Movement Timing Asymmetry on the Perception of Dynamic Facial Movement Naturalness

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Abstract

Objective—To determine the threshold for detection of side-to-side facial movement timing asymmetry, and measure its impact on perceived facial movement naturalness.

Methods—Video recordings of five healthy facial movements (eye blink, rapid brow raising, slow brow raising, smiling, and lip depression) were edited to introduce six levels of side-to-side timing asymmetry ranging from 33-267 ms. Participants (N=58) viewed movement video clips through an online survey service, indicating which clips had side-to-side asymmetry in movement, and whether movements seemed natural or unnatural on a 5-point scale.

Results—There was a significant difference among movements in asymmetry detection threshold ($p < .01$). At 33 ms of movement asymmetry, 81% of participants perceived all movements as symmetrical except for blink, which was perceived as symmetrical by only 33% of participants. At 67 ms of asymmetry, blink was perceived as symmetric by only 2% of participants, whereas the other movements were perceived as symmetrical in a range of 12-43%. At 100 ms, only 3% of participants judged the movements as symmetrical across all facial zones. There was a strong correlation between naturalness ratings and amount of delay across movements ($R = .823$), with greater asymmetry being judged as progressively less natural ($P < .001$). Blink was judged as less natural at across all time delays compared to all other movements ($P < .005$).

Conclusions—Side-to-side asymmetry in blink timing is detected sooner and viewed as less natural compared to asymmetry of the brow and lips. These findings will help set timing goals for facial pacing technologies treating unilateral paralysis.

Introduction

Facial paralysis is a devastating condition; afflicted patients suffer functional deficits, aesthetic issues, and profound psychosocial challenges (^{1,2,3}). In addition to traditional surgical interventions involving nerve and muscle transfers, some authors have proposed neural prosthetic approaches that could potentially reanimate the face by electrically stimulating facial nerves and/or paralyzed muscles (^{4,5}). The most promising application of

functional electrical stimulation (FES) for facial reanimation would involve instances of unilateral paralysis, where one side of the face has normal movements that can be detected and used to 'pace' stimulation of the contralateral, paralyzed face. Although theoretically feasible, this approach harbors several technological challenges in achieving rapid, accurate detection and subsequent FES reanimation of movements.

In order to make informed decisions regarding implementation of neural prosthesis components (i.e. weighing the trade-off between system component speed versus invasiveness), the threshold for detection of side-to-side movement asymmetry and its perceptual impact on movement naturalness must be established. Potential hardware interfaces with the body, for first detecting and then eliciting facial movements, introduce varying degrees of delay in this sequence. For example, electromyographic-based detection of blink can occur simultaneously with (or even precede) visible movement⁽⁶⁾, but bioelectric recordings are prone to signal interference from adjacent muscles, which could be difficult to distinguish and eliminate. Other potentially more accurate detection strategies, such as accelerometry or image-based monitoring may introduce delay, causing conspicuous side-to-side asymmetry in facial movements. On the stimulation side, implanted electrodes generate relatively fast movement, while less invasive body surface stimulation may introduce delay that might affect perceived gesture naturalness. Although studies have examined the degree of lateral asymmetry detectable in static images of the face^(7,8), the detection thresholds and perceptual impact of dynamic timing asymmetry has not yet been determined.

The goal of this study was to quantify the amount of time delay between movements on the left and right sides of the face that causes observers to detect asymmetry in facial movement. We also examined whether certain specific facial movements (i.e. eye blink, brow raise, smile, or lip depression) had different time delay detection thresholds, and investigated to what extent side-to-side facial movement asymmetry affected subjective rating of movement naturalness. Taken together, these data will help guide the design of neural interfaces for facial reanimation.

Materials and Methods

We performed a prospective perceptual assessment of facial movement video clips presented to participant volunteers through an internet web site (Surveygizmo.com; Widgix, LLC, Boulder, CO). The video clips were recorded from a 26 year old female who provided informed consent under a study protocol approved by the Massachusetts Eye and Ear Infirmary Institutional Review Board.

Video clip preparation

Video recordings of facial movements were obtained with the subject seated upright in a clinical examination chair, with the back of her head resting firmly against a padded headrest in order to minimize head movements. Recordings were made under even illumination (StudioMax II 320 umbrella lights by Photogenic Inc.) using a Canon HF200 digital video recorder (1080p, 2892 kbps, 29.97 frames/s) while the subject repeated five particular facial movements, including eye blink, rapid and slow brow elevation, smiling,

and lip depression. Recordings were reviewed to select a single representative rendition of each movement type, and the digital video files were edited in software (Corel VideoStudio Pro X3) to make them uniformly 3 s in length. Each video clip had at least 467 ms of neutral posture preceding each movement. Figure 1 presents the durational aspects of each movement, including total duration, latency from start to maximum excursion, duration of peak excursion, and return to a neutral facial posture.

Facial movement video clips were edited to ensure complete side-to-side symmetry of movement by splitting the screen down the vertical midline of the face and duplicating one side of the face as a mirror-image onto the opposite side. These symmetrical (baseline) videos were edited to create additional video clip versions with one side of the face delayed 1, 2, 3, 4, 6 and 8 frames relative to the other side (29.97 frames/s, generating approximately 33.34 ms/frame of introduced side-to-side delay). Moreover, the side of the face that was delayed was randomly chosen for each degree of delay. A white strip 10 pixels wide was placed on the face midline on all videos to obscure the right-left break in image continuity that may otherwise appear when one side was delayed relative to the other side (see Figure 2).

Video clip presentation for perceptual assessment

Perceptual assessment of video files was conducted using an online survey service (Surveygizmo.com). Potential participants were sent an email with a brief description of our study goals and a link to the survey web site. The link opened an introduction page in the participant's default web browser, providing the following study description and directions:

“When we make facial expressions or blink, parts of our face might move with timing differences from right-to-left.

We are studying how much right-to-left difference in movement there needs to be before people notice, and whether these right-to-left differences look natural or unnatural.

You will watch short video clips of a woman's facial expressions during which one side may be delayed relative to the other side. For each clip you will report whether you noticed a delay.

If you noticed a delay then you will be asked to rate the facial expression as natural (normal, typical) to unnatural (disturbing, distracting) on a 5-point scale.

You will view many 3-second video clips, and the survey is expected to take about 8 minutes once you begin.

We can't use incomplete survey results, so we hope you complete all of the survey items, but you can quit at any time if you do not wish to continue.

Scroll down and click “Next” page to view a demonstration.

We appreciate your participation!”

The second page of the survey presented a demonstration video showing symmetrical (baseline) versions of all of the movements that would be presented in the test. Also

presented on this page was an example of the 5-point Likert scale of “Natural” to “Unnatural” that participants were to complete for each video if they indicated seeing side-to-side asymmetry in movement timing. This page also provided a pull-down menu for participants to indicate what device they were using to complete the survey (laptop, desktop, tablet or smartphone), their gender, and their age.

After the introductory pages, participants viewed the 35 video clips one at a time in random order, clicking a “next” button after reporting whether they detected side-to-side delay and rating movement naturalness (for each video in which they detected a side-to-side delay). Video files were streamed on the survey platform from an online media service (YouTube LLC, San Bruno, CA) with a frame size of 700 x 576pixels in the web browser. The media service provided video data buffering that allowed playback on devices with a wide range of processing capabilities and internet bandwidth without interruption or distortion. If participants encountered playback discontinuity they were able to repeat viewing through the video window control panel.

Data analysis

Test results were downloaded from the survey service to an Excel spreadsheet (Microsoft Corporation, Redmond, WA) and screened for outlying respondents. A Friedman non-parametric test was conducted to determine if significant differences were present among naturalness ratings of the video clips across different degrees of delay asymmetry. A Wilcoxon Signed-Rank test was used to compare naturalness scores for each movement versus all other movements (10 comparisons) within each level of split-screen delay. A stringent alpha level of $P < 0.005$ was used for each set of 10 pair-wise comparisons to mitigate alpha inflation. Post hoc analysis with the Wilcoxon Signed-Rank test was performed to examine differences between degrees of frame delay within movements using a Bonferroni correction to maintain an aggregate alpha level of $P = 0.05$ for rejecting the null hypothesis.

Results

Sixty-three recipients of the email request for participation in this study completed the video assessment survey. Of these respondents, 5 ($\approx 8\%$) had correlations between the number of frames delayed and naturalness ratings that were more than two standard deviations lower than the average correlations from all of the respondents combined. It was assumed that participants would perceive movements with greater side-to-side timing asymmetry as less natural, therefore, these 5 respondents were considered outliers and were removed from the survey results, leaving 58 contributing participants. There were 33 female and 25 male participants, with ages ranging from 19-73 (average of 41.2) years. There were no significant differences between males and females, as well as no significant differences across age groups (when divided into 5 groups, approximately by decade). Participants reported taking the perceptual test on a desktop computer (47%), laptop (45%), tablet (5%), or smartphone (3%), with no clear difference in test outcome based on device (although small group sizes for tablet and smartphone precluded statistical examination).

Participants were presented with the facial movement video clips one at a time in random order. When there were 0 frames of delay between the two sides of the face, an average of 95% of the participants indicated that the face moved symmetrically across the 5 movements (see Figure 3). There was a significant difference across facial movements when one side was delayed by 33 ms (1 frame) relative to the other side ($\chi^2(4, N = 207) = 15.874, p < .01$), wherein 81% of participants perceived facial movement as symmetrical for all movements combined except for blink, which was perceived as symmetrical by only 33% of participants. There was also a significant difference across facial movements when there were 67 ms of split-screen delay (2 frames; $\chi^2(4, N = 64) = 26.312, p < .01$). With 67 ms of asymmetry, blink was rarely (2%) perceived as symmetrical, whereas the other movements were perceived as symmetrical in a range of 12-43% (see Figure 3). With 100 ms (3 frames) of relative delay, an average of only 3% of participants judged the movements as symmetrical.

When a video was judged as symmetrical, the naturalness score was assigned a value of zero. When a participant reported seeing asymmetry, the survey web page presented a 5-point Likert scale for judging facial movement naturalness, ranging from 1 (natural) to 5 (unnatural). There was a strong average correlation between naturalness ratings and amount of delay across movements (average $R = .823, SD = .04$), with greater asymmetry in split-screen movement being judged as progressively less natural. The relationship between movement asymmetry and naturalness ratings was statistically examined with the Friedman non-parametric test, which generated a rank ordering for each subject based on Likert scale values (perception of naturalness) versus the 7 levels of split-screen delay within each movement, and compared rankings among participants in relation to a chi square distribution. There was a statistical difference in the ranks of the delay amount for all movements (Five tests; $\chi^2(6, N = 58) = 258$ to 281 , all $P < .001$), confirming the impact of delay on perceived naturalness. Rankings were averaged across participants and are presented in figure 4, revealing a consistent relationship between split-screen time delay and naturalness score for each movement.

Naturalness scores differed by movement within multiple levels of split-screen delay (see Figure 5). A Wilcoxon Signed-Rank test revealed that blink significantly differed from all other movements at 33, 67, 100 and 133 ms delay (1-4 frames, respectively; $P < .005$). At 200 ms delay, blink differed from slow brow, and at 267 ms delay, blink differed from slow brow and fast brow. Lastly, at 67 ms of delay, slow brow differed from fast brow and lip depression.

Pairwise comparisons were also performed to determine whether each level of split-screen delay significantly differed in median naturalness score among participants from all other levels within each movement. These post-hoc analyses were conducted using the Wilcoxon signed-rank test with a Bonferroni correction, resulting in a significance level of $P < 0.0024$ (significance level of 0.05/ 21 comparisons within each movement). For each compared level of split-screen timing asymmetry, participants typically judged the more symmetrical video as being more natural (i.e. closer to 1 instead of 5 on the Likert scale). The only pairs where this pattern was not significant are listed in table 1.

Discussion

Significant facial asymmetry has been linked to the perception of disfigurement^(9,10), often causing patients to report higher levels of depression⁽¹¹⁾ and lower quality of life scores⁽¹²⁾. These facial asymmetries can come from facial paralysis, lesions, or other changes to the face. Facial lesions have been shown to have an attractiveness penalty⁽¹³⁾ and attract more attention⁽¹⁴⁾ than other parts of the face. Pictures of individuals with facial paralysis have been ranked as less attractive than individuals without facial paralysis⁽⁸⁾, and typical visual scan-path patterns are redirected toward the side with facial paralysis⁽⁷⁾, a crooked nose⁽¹⁵⁾ or a facial lesion⁽¹⁴⁾. Surgical reconstruction and reanimation techniques can potentially address the causes of facial asymmetry, and it is important to know the relationship between side-to-side difference in movement range and/or timing and the resulting perception of movement naturalness. This is particularly true for the development of facial movement pacing systems, since the implementation of different hardware solutions for movement detection and elicitation can introduce different amounts of side-to-side timing asymmetry, and the perceptual impact of timing delays must be considered in the early stages of system design.

One of the most commonly utilized parameters for quantification of surgical outcomes is measurement of recovery of excursion in the involved facial region⁽¹⁶⁻¹⁹⁾. Paradoxically, Paletz et al. have shown that within normal subjects, amount of variation of oral commissure excursion between each side can be as much as 52%⁽²⁰⁾. Although they observed varying distances of excursion, the vector of excursion was consistently symmetric in smiles of normal subjects. This suggests that the vector of excursion is just as important as the net distance of excursion when one aims to achieve natural facial movement through FES or/and surgical techniques in patients with unilateral facial paralysis.

These studies suggest that multiple parameters need to be considered when evaluating facial dysfunction and setting movement timing goals for facial reanimation (e.g. pacing). Often times, the net excursion has been utilized in the literature, likely because spatial measurement is reliable and objectively quantifiable⁽²¹⁻²³⁾. However, for more comprehensive analysis of facial evaluation, one should consider the dynamic components of facial movement, such as synchronicity and symmetry of movements. Our study demonstrates that there are different time-delay thresholds for detection of dynamic asymmetry in each distinct region of the face, with subjective naturalness rating and the length of time delay demonstrating a strong correlation. Specifically, pacing of blinks apparently needs to occur with less than 33 ms of side-to-side delay in order to remain below the detection threshold. Moreover, blinks were perceived in our study as significantly less natural than all of the other gestures across the first few levels of delay, likely stemming from their fast movement and relatively short duration. Slower movements, such as slow brow raise and smile, were more often perceived as symmetrical at 33 and 67 ms of side-to-side asymmetry, and were generally perceived as more natural at these time delays compared to the other movements. These results indicate that side-to-side time delays in faster movements, such as blinking and rapid brow raising, have the lowest threshold for asymmetry detection, whereas slower movements, such as smiling and slow brow raising are less obviously asymmetric, even with longer side-to-side time delays. These findings may be

expected, since unilateral delays of faster movements will generate greater side-to-side differences in facial appearance in less time than delays in slower movements, and when the movements are brief, the direction of rapid movements become out of phase with even small amounts of side-to-side delay (i.e. blink; see Figure 1).

To the best of our knowledge, the present study is the first to examine the detection thresholds of side-to-side timing asymmetry in dynamic facial movements. In addition to differences in movement speed discussed above, there are further possible explanations for why different movements had different detection thresholds. For example, eye-tracking studies demonstrate that when individuals look at human faces, they follow a scan path forming a triangle among the eyes, nose, and mouth (cf. ²⁴), with particular attention paid to the eyes and mouth for emotional faces (²⁵⁻²⁷). Moreover, our findings of the low detection threshold for blink asymmetry could possibly be attributed to a disproportionate amount of time the participants spent looking at the eyes due to the initial neutral expression (lasting 467 ms) preceding the initiation of movements, because a recent eye-tracking study found that when healthy faces were portraying neutral, angry, or sad expressions, there was greater focus on the eyes than other regions of the face (²⁸). Therefore, the neutral baseline start of each video may have predisposed observers to focus on the eyes and detect differences in their movement relatively more quickly than movements in other facial regions.

There are known left to right facial asymmetries in dynamic expressions based on what emotion is being portrayed, and it is common to encounter side-to-side expression timing differences across and within individuals (see ²⁹ for review). As a result, it is likely that people naturally expect greater degrees of timing asymmetry in some expressions compared to others. For example, healthy individuals do not typically exhibit asymmetrical blink, but may exhibit an asymmetrical smile or brow raise. Therefore, it is possible that observers naturally have a higher detection threshold and more tolerance for asymmetry in these latter expressions, consistent with the present findings.

Perceptual evaluations of movement asymmetry in this report are a useful starting point for setting facial pacing timing goals, but may require further study given the complexity and nuances of facial movement perception. Although we obtained consistent differences in the detection and perceptual impact of timing asymmetries for facial movements spanning multiple zones, and we did not determine what particular aspects of side-to-side differences bring about the perception of asymmetry, and to what degree different movement rates within each facial zone have on naturalness perception. Moreover, future work is needed to determine whether the amount of excursion during facial movement, in the absence of timing considerations (such as synchronicity or velocity), demonstrates the same strong inverse correlation between degree of asymmetry and perception of naturalness. It would also be useful to determine whether asymmetrical facial movements produced by male participants, and by appreciably older or younger individuals would be viewed differently than the 26 year old female appearing in the video clips of this study. In addition, the perceptual judges in this study were instructed to look for asymmetry in particular facial movements, but it is unknown what degree of timing asymmetry would have gone unnoticed without such prompting, or whether the same perceptual findings would have been obtained in face-to-face encounters rather than our video task with a right/left dividing line in the

field of view. Some of these answers might best be attained through performance testing of facial pacing systems as they are developed, but the present findings provide an indication of what movement latencies those initial system should strive to achieve.

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Figure 1.

Facial movement durations shown as the time taken from the initiation of movement to maximal excursion (in white), the time that maximal excursion was maintained (in black), and the return from maximal excursion to a neutral position (in gray). The lowest lines represent 1, 2, 3, 4, 6, and 8 video frames of delay, which were the delay increments introduced to one side of the face in the perceptually assessed video clips. Note that the fastest movements (blink and fast brow raise) had maximal excursions held for less than one video frame, which are shown as instantaneous lines.

Figure 2.

Video still frames representing facial movement examined in the perceptual assessment test. Examples are from the symmetrical (baseline, or non-delayed) video version, including a representative neutral position (A); brow raise (B); blink (C); smile (D), and lip depression (E). Movement B-E represent maximal movement excursions, represented by the black bars in Figure 1. Slow and fast brow raise had similar maximal excursions, and are represented by a single still frame (B).

Figure 3.

Reported symmetry of facial movement as a percentage of participants (N=58) for 5 movements across 7 levels of potential side-to-side difference in movement timing, ranging from 0-264 ms delay. For all movements, video clips with 0 ms side-to-side delay were typically correctly reported as being symmetrical, and 99 ms of timing difference was typically identified as not symmetrical. The perception of movement symmetry differed by movement at delays of 33 ms and 66 ms. The dotted line at 50% represents detection threshold.

Figure 4. Median ranks of naturalness scores averaged across participants (N=58). For each of the 5 perceptually assessed movements, naturalness scores consistently ranked as less natural (higher value) with increases in side-to-side asymmetry of movement.

Figure 5.

Median naturalness scores for all participant responses are plotted for each movement at 7 levels of asymmetry in side-to-side movement timing. Note how blink is perceived as relatively unnatural within the first several levels of delay compared to the other movements, and that slower movements such as smile and slow eyebrow raising are generally perceived as more natural across multiple levels of asymmetry compared to faster movements.

Table 1

Non-significant ($P > 0.0024$) comparisons of split-screen time delays by movement.

Blink	Lip depression	Fast brow	Slow brow	Smile
67 ms vs. 100 ms	0 ms vs. 33 ms	0 ms vs. 33 ms	0 ms vs. 33 ms	0 ms vs. 33 ms
67 ms vs. 133 ms	100 ms vs. 133 ms	200 ms vs. 267 ms	100 ms vs. 133 ms	
100 ms vs. 133 ms			200 ms vs. 267 ms	
100 ms vs. 200 ms				
133 ms vs. 200 ms				