Research Article

Haptic Recognition of Static and Dynamic Expressions of Emotion in the Live Face

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ABSTRACT—***If humans can detect the wealth of tactile and haptic information potentially available in live facial expressions of emotion (FEEs), they should be capable of haptically recognizing the six universal expressions of emotion (anger, disgust, fear, happiness, sadness, and surprise) at levels well above chance. We tested this hypothesis in the experiments reported here. With minimal training, subjects' overall mean accuracy was 51% for static FEEs (Experiment 1) and 74% for dynamic FEEs (Experiment 2). All FEEs except static fear were successfully recognized above the chance level of 16.7%. Complementing these findings, overall confidence and information transmission were higher for dynamic than for corresponding static faces. Our performance measures (accuracy and confidence ratings, plus response latency in Experiment 2 only) confirmed that happiness, sadness, and surprise were all highly recognizable, and anger, disgust, and fear less so.***

Visual face processing is of strong evolutionary significance across many biological species because the face carries different categories of information that are all critical to survival: friend or stranger? predator or prey? potential mate? A substantial research literature in cognitive science and neuroscience has established that face processing is a crucial function of visual perception not only in humans, but in other species as well.

Person identification by vision is highly dependent on the ability to successfully differentiate, recognize, and identify many different faces. Past research has shown that the hallmarks of visual processing of faces, relative to visual processing of other object categories, are that it is highly practiced (e.g., Gauthier, Curran, Curby, & Collins, 2003), based predominantly on overall configuration (e.g., Maurer, Le Grand, & Mondloch, 2002), orientation-specific (e.g., Farah, Tanaka, & Drain, 1995; Sergent, 1984), and identity-specific (e.g., Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). Most researchers agree that a subset of visual abilities, sometimes referred to as a face module, may be dedicated to such processing (e.g., Kanwisher, McDermott, & Chun, 1997).

The enduring structure of an upright face defines a set of configurally arranged geometric features that, together with other distinguishing characteristics such as pigmentation and color, uniquely portray an individual face despite moderate changes in the observer's position and lighting. Such invariants offer the visual system a variety of sensory cues that afford excellent discrimination, recognition, and identification of individual faces.

The human face is vitally important in communicating emotions both verbally and nonverbally (Darwin, 1872/1955). Facial expressions of emotion (FEEs) may be regarded as the converse of facial identity; that is, invariant features of an emotion apply universally across, as opposed to within, faces. These invariants of FEEs are derived from static musculoskeletal patterns and from momentary changes in these patterns over time. Ekman and Friesen (1975) carefully described facial action patterns, or FACs, which have visibly detectable consequences that humans successfully use to process FEEs in photographs (e.g., Wehrle, Kaiser, Schmidt, & Scherer, 2000), line drawings (e.g., Etcoff & Magee, 1992), and simulated dynamic presentations (e.g., Calder, Young, Perrett, Etcoff, & Rowland, 1996). Ekman and other researchers have shown that across cultures, people recognize a small number of emotional categories, including happiness, sadness, anger, disgust, fear, and surprise.

Research on facial displays of emotion has generally used static 2-D spatial representations, such as photographs and schematic drawings. Of particular relevance to the current study is the relative efficacy of static versus nonrigid, dynamic displays in communicating emotion. Experimental results have been somewhat mixed. Early results confirmed an advantage in

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recognition accuracy for dynamic over static FEEs when the stimuli were reduced point-light displays (Bassili, 1978). However, subsequent researchers have generally found minimal benefit for full, dynamic displays of intense facial expressions (e.g., Kamachi et al., 2001; Wehrle et al., 2000). Thornton and Kourtzi (2002) documented no advantage for facial motion during the priming phase of an expression-matching task. Edwards (1998) showed that people could use temporal cues to determine the proper progression of emotional expressions at better than chance levels; however, the results of that temporal-sequencing task may not apply to real-time changes that occur during the production and recognition of emotional expressions. We know of only one study (Ambadar, Schooler, & Cohn, 2005) that has demonstrated a robust benefit for dynamic expressions over single or multiple static displays. The dynamic effect observed in that study was specifically linked to the perception of change per se.

Face processing is not limited solely to vision. Haptically accessible information about structurally invariant 3-D contours and distinctive material properties, such as skin texture and compliance (perceived in terms of skin smoothness, softness, firmness, etc.), accounts for the recent discovery that humans are capable of haptically identifying individual faces at levels well above chance. This fascinating finding, initially demonstrated by Kilgour and Lederman (2002) with both live faces and rigid face masks, has since been confirmed by several studies (Casey & Newell, 2005; James, Servos, Huh, Kilgour, & Lederman, 2006; Kilgour, de Gelder, & Lederman, 2004; Kilgour, Kitada, Servos, James, & Lederman, 2005; Kilgour & Lederman, 2006; Pietrini et al., 2004).

Producing emotional expressions alters one's facial appearance in ways that may be haptically detectable. Humans are haptically sensitive to both spatial (albeit coarse) and temporal changes in the structural properties of objects. In addition, they are particularly sensitive to spatiotemporal variation in an object's material properties, such as texture, compliance, and thermal attributes (Jones & Lederman, 2006; Klatzky & Lederman, 2003). Accordingly, a wealth of tactile and haptic information is potentially available for the haptic recognition of live FEEs, particularly when they are displayed dynamically. We therefore made what may be a surprising prediction, namely, that people are capable of using their hands to recognize universal emotions portrayed by live faces. Our results confirmed that with minimal training, people can indeed recognize the universal expressions of emotion successfully by hand. In addition, we found that accuracy is consistently better with dynamic, as opposed to static, displays of FEEs.

THE EXPERIMENTS

We assessed subjects' ability to haptically recognize six universal FEEs—anger, disgust, fear, happiness, sadness, and surprise—in live facial displays produced statically (Experiment 1) and dynamically (Experiment 2). Corresponding visual-control data consisted of the visual recognition of static or dynamic FEEs in video clips made with the same actors. For purposes of clarity, we present the two experiments together.

Method

Subjects

Fifty-three experimentally naive, predominantly female undergraduates, ages 17 through 25 years, participated (Experiment 1: 20 in the haptic condition, with 10 subjects per actor; 8 in the visual-control condition, with 4 subjects per actor; Experiment 2: 20 in the haptic condition, 5 in the visual-control condition). By self-description, all were right-handed and had both normal hand function and normal (or corrected-to-normal) vision and hearing. Each person received $10 for participating.

Actors

Two trained female actors (ages 20 and 66 years) with amateur or professional acting experience were employed in Experiment 1. As their results were very similar, Experiment 2 used only one of these actors.

Haptic and Visual-Control FEE Displays

For Experiment 1, the actors were trained to generate the six universal FEEs statically until a group of four judges could agree as to which emotion each visual expression portrayed. Only the FEE for fear produced less than perfect agreement. The static displays lasted up to 12 s, which was deemed sufficient for haptic exploration on the basis of pilot work. For Experiment 2, the second actor was also trained to produce the FEEs dynamically, by showing four cycles of neutral expression to target expression, with no pauses between cycles. The dynamic displays lasted approximately 8 s. This duration matched subjects' overall average haptic response times in Experiment 1, estimated with a stopwatch from the video recordings of the haptic trials (see the next section). The actors' eyes were closed in all haptic and visual-control conditions.

For the visual-control conditions, two sets of video clips were produced: static PowerPoint displays for Experiment 1 and dynamic PowerPoint displays for Experiment 2.

Procedures and Experimental Designs

In the haptic conditions, subjects wore a blindfold, as well as hearing protectors to eliminate any inadvertent emotion-related sounds made by the actor. In both experiments, they were instructed how to initially place their hands on the actor's live face—lightly to avoid constraining the actor's movements, and in a manner predetermined to maximize contact with the different features of the face, as shown in Figure 1. In Experiment 1, the subjects were then allowed to explore the static face freely. In Experiment 2, the experimenter then cued the actor to begin dynamically cycling continuously between a neutral expression

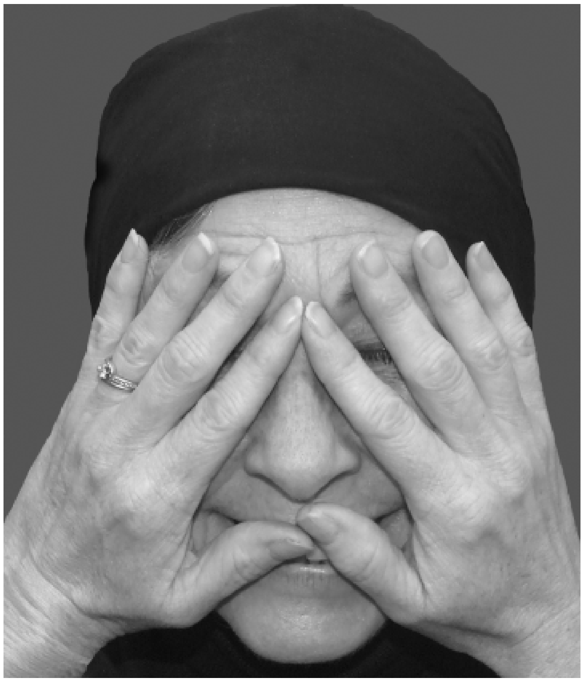

Fig. 1. Manual start position for the haptic conditions in Experiments 1 (static displays) and 2 (dynamic displays).

and the target expression (for a maximum of four cycles); the subjects' hands remained statically in place on the actor's face until the subjects were ready to respond. Obtaining precise response times in addition to the other dependent variables was manually impossible with only one experimenter. However, a continuous video record of each individual session in Experiment 1 was produced, and from this record the overall average response time was estimated for the static trials (i.e., 8 s). In Experiment 2, it was possible to record the number of cycles on each trial as a formal, albeit coarse, measure of response time. The six possible responses were repeated orally on demand in alphabetical order throughout the experiments.

During practice for the haptic conditions, the six different static or dynamic FEEs were presented once in alphabetical order. Subjects were then presented with one set of the six basic expressions in random order and instructed to identify each from the closed set of FEE names.[1] They were instructed to be as fast and as accurate as they could, and received feedback after each response. Subjects were allowed to reexamine any expression before beginning the formal experiment. Following this practice period, the haptic displays were presented without feedback.

Both experiments had one within-subjects factor (emotion), and Experiment 1 had an additional between-subjects factor (actor). During the test phase, each of the six emotions was repeated four times, for a total of 24 trials. The FEEs were presented in totally random order to minimize guessing. At the end of the experiment, subjects listed in order of importance the features on which their haptic recognition judgments were based and rated their overall confidence for each type of FEE (1 = *not at all confident*; 7 = *extremely confident*). The haptic sessions lasted about 1 hr.

The visual-control conditions employed the same experimental design as the haptic conditions. The visual stimuli consisted of PowerPoint displays that were created from videotapes of the same actor (or actors) who produced all static or dynamic stimulus displays used in the corresponding haptic condition. Subjects were required to verbally identify the visually presented FEEs as quickly and as accurately as possible. The control sessions lasted approximately 15 min each.

Results

Accuracy

The means and standard errors for each emotion, display mode, and modality are shown in Figure 2a. The overall mean haptic accuracy for statically expressed emotions was 50.6% (SEM = 0.03). The corresponding accuracy for dynamic FEEs was statistically higher, 74.0% ($SEM = 0.02$), $t(238) = 5.54, p_{\text{rep}} > .99$ (Killeen, 2005), Cohen's $d = 0.71$.

The individual subjects' means for each emotion (based on four repetitions) were entered in analyses of variance (ANOVAs) with a Greenhouse-Geisser correction. In Experiment 1, the Actor × Emotion ANOVA showed no main effect or interaction effect involving actor. As there were very few statistical differences between actors for any performance measure, we do not discuss this factor further. The main effect of emotion was significant in Experiment 1, $F(3.82, 68.72) = 6.61$, $p_{\text{rep}} > .99$, $\eta_p^2 = .27$. In Experiment 2, a one-way ANOVA also showed a strong effect of emotion, $F(3.66, 69.61) = 19.69$, $p_{\text{rep}} > .99$, $\eta_p^2 = .51$. One-tailed t tests were performed to test whether haptic recognition was significantly better than chance (16.7%). Only static fear produced chance-level performance; all other p_{rep} values were greater than .97. As is evident in Figure 2a, the means for static FEEs clustered into two main groups: a lower-accuracy set including anger, disgust, and fear, and a higher-accuracy set including happiness, sadness, and surprise. The means for dynamic FEEs clustered into the same two subgroups.

Corresponding visual-control means for the static FEEs were at or near 100% except for fear; there were no errors when the dynamic FEEs were recognized visually.

Haptic Confusion Errors and Amount of Information Transmission

Haptic confusions across expressions were collated for each experiment. Responses were normalized by the total number of times a given response was chosen, to eliminate response biases. These data are presented in Table 1. There are four notable patterns, with the first three relevant to both static and dynamic displays. First, the FEE subgroup composed of anger, fear, and

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[1] Thus, strictly speaking, a categorization, as opposed to a recognition, paradigm was used.

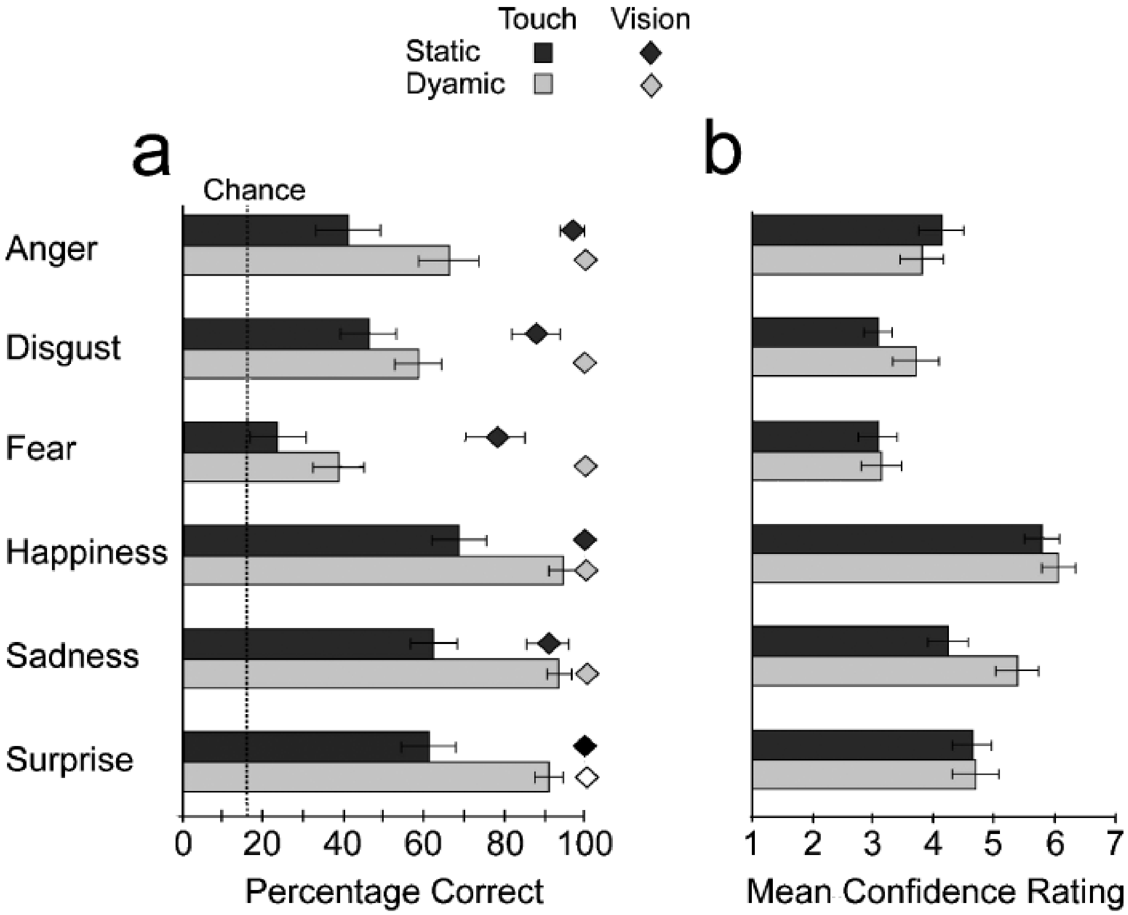

Fig. 2. Mean recognition accuracy (a) and confidence ratings (b) in Experiments 1 and 2. Results for each facial expression of emotion are shown separately for the two display modes (static and dynamic) and for the two modalities (touch and vision). Confidence ratings were made on a scale from 1 (*not at all confident*) to 7 (*extremely confident*). Error bars indicate standard errors of the means.

disgust tended to elicit the greatest number of confusions (although the specific patterns are not symmetric—hence, do not act like a distance metric—and differ for the two display modes). Second, the subgroup composed of happiness, sadness, and surprise elicited very little confusion with other FEEs. Third, FEEs of the low-performance subgroup tended to be broadly confused with FEEs across both subgroups; in contrast, FEEs of the high-performance subgroup tended to be confused primarily with FEEs in the low-performance subgroup. Fourth, for each stimulus expression, the confusions were not equally distributed across all response options: Anger was particularly likely to be confused with surprise (static and dynamic), disgust with sadness (static) and anger (dynamic), fear with many other FEEs (static and dynamic), happiness with fear (static), and both sadness and surprise with anger, disgust, and fear (mainly static).

From the confusions, it was possible to derive a measure of information transmission in bits (Tan, 1997). The mean overall amount of information transmission was 1.54 ($SEM = 0.06$) bits for static FEEs and 1.82 ($SEM = 0.01$) bits for dynamic FEEs. The optimal information transmission for this matrix size is 2.59 bits, and chance is 0 bits. Thus, both static and dynamic expressions were recognized well above chance but below the optimum value.

Response Latency and Confidence

Patterns in the response latencies (number of expressive cycles, maximum of four; Experiment 2 only) and confidence ratings (Experiments 1 and 2) are generally consistent with the division into two FEE clusters revealed in the accuracy scores. A test of least significant differences ($\alpha = .05$) on paired comparisons of the mean response latencies for the dynamic faces showed two statistically different clusters: Anger, disgust, and fear were recognized more slowly (2.60 to 2.78 cycles), and happiness, sadness, and surprise were recognized more quickly (2.00 to 2.14 cycles). The mean number of cycles (neutral expression to target expression) required for visual recognition ranged from 1.4 (disgust) to 1.0 (happiness, sadness, and surprise).

With respect to the confidence ratings, the main effect of emotion was highly significant in both Experiments 1 and 2,

TABLE 1

Confusion Matrices for the Static (S) and Dynamic (D) Displays

	Response											
	Anger		Disgust		Fear		Happiness		Sadness		Surprise	
Stimulus	S	D	S	D	S	D	S	D	S	D	S	D
Anger	**.49**	**.66**	.12	.03	.15	.12	.01	.00	.01	.00	.28	.19
Disgust	.09	.19	**.41**	**.67**	.08	.12	.00	.02	.31	.11	.04	.00
Fear	.21	.11	.17	.24	**.31**	**.61**	.21	.09	.10	.08	.07	.08
Happiness	.01	.01	.07	.00	.16	.04	**.69**	**.88**	.03	.00	.06	.01
Sadness	.09	.00	.12	.06	.16	.02	.03	.00	**.55**	**.82**	.01	.00
Surprise	.12	.03	.11	.00	.13	.10	.06	.00	.00	.00	**.54**	**.72**
Total number of responses	68	80	90	70	61	51	80	86	91	91	90	101

Note. Cell entries were normalized using the total number of responses within the associated column to produce proportions. Cells along the diagonal (highlighted in boldface) indicate correct responses.

$F(3.52, 63.40) = 16.21$, $p_{\text{rep}} > .99$, $\eta_p^2 = .47$, and $F(3.78, 71.89) = 11.75$, $p_{\text{rep}} > .99$, $\eta_p^2 = .38$, respectively. In Figure 2b, the mean confidence scores for both static and dynamic displays reveal the same two FEE clusters as do the other performance measures. In addition, the mean confidence rating tended to be marginally higher for the dynamic displays ($M = 4.48$, $SEM = 0.18$) than for the static displays ($M = 4.18$, $SEM = 0.23$), $t(238) = -1.33$, $p_{\text{rep}} > .83$, Cohen's $d = 0.17$.

Subjective Importance of Facial Regions

Ekman and Friesen's (1975) FAC analysis highlights the differential involvement of facial muscles across emotions and has potential consequences for visual perception. In this article, we suggest that to the extent that these same musculoskeletal changes may be detected haptically, they will have important consequences for haptic face perception as well. Although feature differences among FEEs were not the primary focus of our study, we examined subjects' subjective reports of diagnostic regions and their relative importance for both static and dynamic FEEs. We reduced the original pool of facial regions to a more manageable set of eight categories: eyes plus eyebrows, cheeks, nose, mouth, lips, teeth, jaw plus chin, and a general facial feature category (e.g., face shape, tension, general facial movement). Responses to our questionnaires for static and dynamic faces revealed five distinct patterns. First, the eye-eyebrow region and the mouth-lip region were both very important for all static and dynamic expressions. Second, the cheeks were uniquely diagnostic of happiness. Third, although infrequently mentioned, the jaw tended to be weighted more strongly when expressions were dynamically produced than when they were statically produced. Fourth, the nose was not strongly diagnostic of any expression, perhaps because related cues were not easily detected. Fifth, although the teeth were rarely mentioned, they were listed most frequently for dynamic anger.

GENERAL DISCUSSION

Research on the nature of haptic processing has highlighted an important distinction regarding the relative effectiveness with which the visual and haptic systems process the concrete world. It is well known that compared with vision, the haptic system does not effectively process the spatial details and overall spatial configuration of either 2-D raised-line drawings of common objects or 3-D planar objects made of a homogeneous material (Lederman & Klatzky, 1993). Processing 2-D shapes is particularly difficult by touch because the fingertip is not as spatially acute as the eye; moreover, the spatial information must be extracted sequentially over time during manual exploration. However, vision is not as effective as haptics when it comes to processing material properties.

Studies listed in the introduction have shown that humans are capable of haptically recognizing the identity of unfamiliar live faces and face masks with accuracy levels well above chance. The current study emphasizes the rich array of information potentially available to the haptic perceiver in expressions of emotion in live facial displays. Despite subjects' minimal training and the variability inherent in live-face displays, haptic recognition was statistically greater than chance for all static FEEs except fear, and for all dynamic FEEs. The two actors yielded similar results, lending greater generality to these findings. In addition, confidence ratings were at or above the middle of the scale, indicating that subjects felt fairly comfortable recognizing FEEs by hand.

The musculature of the face and its changes over time provide valuable sensory information that may be used by vision to judge FEEs. We have argued that there are informative sensory cues in FEEs that may be accessed by hand as well as by eye. Some of the sensory cues may be modality-specific, although others may be accessible via both vision and touch. Presumably, structural information (e.g., jaw shape) and surface texture (e.g., corrugations of the skin) are available to both visual and haptic systems. Color information (e.g., flushing) is necessarily limited to visual access, whereas compliance cues (e.g., skin firmness) are accessible primarily via haptic access.

The finding that fear was recognized relatively poorly by touch replicates our own visual-control results, as well as those obtained by Palermo and Coltheart (2004) with static visual photos. Such a broadly observed result suggests that it is the data-limited nature of the signal that led to poor haptic performance, rather than a deficit that is modality-specific. Beyond the notable deficit for fear, the six FEEs were not equally recognizable by hand. Regardless of display mode, accuracy, response latency (number of expressive cycles), and confidence ratings revealed two major FEE groupings, with happiness, sadness, and surprise all highly recognizable and anger, disgust, and fear less so. The low-performance group produced more confusions than the high-performance group, and the erroneous responses to FEEs in the low-performance group were spread broadly across the two groups; in contrast, confusions within the high-performance group were largely restricted to responses invoking the low-performance FEEs.

We suggest that distinctiveness may underlie the differences in performance across FEEs. High distinctiveness conveys a dual advantage, in that it provides a more diagnostic signal for the FEE while reducing its confusability with other FEEs. What types of factors, then, might contribute to the haptic distinctiveness and confusability patterns observed in this study?

We suggest three viable possibilities. First, FEEs may be distinctive because the facial musculature activates a unique region of the face (e.g., the cheeks in a happy expression) statically, dynamically, or both statically and dynamically (for discussion of this factor with respect to vision, see, e.g., Cunningham, Kleiner, Wallraven, & Bülthoff, 2005; Palermo & Coltheart, 2004). Because primary facial features (e.g., mouth, eyes) are highly spatially separated, the haptic system can likely detect unique regional activation. Second, even if a region is common to more than one FEE, the expressions may be distinctive because of unique qualitative features within that region (e.g., topological features such as mouth open vs. closed; directional features such as brows up vs. down or lips curved up vs. down) or distributed across multiple facial regions. Third, FEEs may vary in terms of quantitative differences pertaining to features within one or more regions (e.g., mouth wide open for surprise, open less wide for anger, and not at all open for sadness). Nevertheless, because the haptic system is not as spatially acute as vision, it may not always detect some of the fine-grain qualitative and quantitative differences, as we discuss next.

FEEs in the low-performance cluster (anger, disgust, and fear) showed high confusability with each other and with at least one member of the high-performance cluster (happiness, sadness, and surprise). Our subjects' subjective responses concerning diagnostic regions suggest that all three low-performance FEEs share several critical areas of activation. In all three cases, the eyes and eyebrows were mentioned most frequently, followed by the mouth. In addition, these three FEEs produce quantitative variations in the size of the mouth opening (none, some, a lot), not all of which may be as discernible to touch as to vision. The same could be said about the skin wrinkling between the eyebrows produced by all three of these FEEs. Anger was strongly confused haptically with surprise, possibly because these intense FEEs share a wide-open mouth, and further, because the hand may not detect the direction of motion of the brow or lips. Disgust was strongly confused with sadness, possibly because the lips curve down in both cases.

FEEs in the high-performance group presumably offer more distinctive information. The most successfully recognized FEE, happiness, offers cues in a unique region (cheeks). Surprise produces distinct qualitative and quantitative differences regarding several features: raised eyebrows, widened eyes, open mouth, and dropped jaw. Static and dynamic sadness are easily distinguished from happiness and surprise by the down-turning of the eyebrows and mouth, by the protruding lower lip, and by the fact that the accompanying movements are relatively small.

It is possible that recognition is better in the dynamic mode than in the static mode for at least two reasons. First, dynamic change stimulates the hands broadly and simultaneously, whereas static displays must be explored sequentially, which increases memory load. Second, subjects can compare a dynamic emotional expression as it is made and unmade with the static neutral expression that commences and terminates the FEE. Change-through-motion is a cue that may be particularly important to the visual recognition of subtle or otherwise reduced expressions of emotion (Ambadar et al., 2005; Bassili, 1978). It is possible that dynamic cues are not as valuable to vision as to haptics because the static structural information about facial features and their configuration is readily available to vision and is sufficient, producing performance close to ceiling levels, particularly in the case of the intense emotions employed here and in most other vision experiments.

CONCLUDING REMARKS

The perception of FEEs is commonly considered the domain of vision. However, emotional expressions displayed on a live face provide a wealth of tactile and kinesthetic cues that permit good recognition by hand, particularly when they are dynamic. Like Tadoma, the tactile method used successfully by a small number of deaf-blind individuals to monitor speech, our work confirms that manual contact with the face constitutes a highly informative communication channel (Reed et al., 1985).Yet unlike Tadoma proficiency—which is rare—haptic face processing is not limited to just a few trained users. Clearly, face processing is not unique to vision.

It is important to keep in mind that even if the facial regions that are most informative for a given FEE are the same for haptic and visual processing, the sensory cues may be different. Consider the FEE of happiness and associated changes in the underlying facial musculature. Vision might detect the upward curvature of the lips, whereas touch might detect a difference in skin compression and possibly tactile motion of the skin under the hands around the region of the lips. In addition, whereas the notable bunching of the cheeks may be easily detected visually as a static change in 3-D structure, the haptic system may detect this bunching as an upward redistribution of skin in the cheek region resulting in a change in facial structure and a change in skin compliance. Clearly, touch is not simply an inferior form of vision. We suggest that studying the haptic system, which is suboptimal for processing precise structural information, may reveal more about other informative FEE characteristics (e.g., redistribution of skin, changes in skin compliance, surface texture) than studying vision, inasmuch as these other characteristics are detected more precisely by hand than by eye.

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