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Haptic Face Processing

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Abstract We present an overview of a new multidisciplinary research program that focuses on haptic processing of human facial identity and facial expressions of emotion. A series of perceptual and neuroscience experiments with live faces and/or rigid three-dimensional facemasks is outlined. To date, several converging methodologies have been adopted: behavioural experimental studies with neurologically intact participants, neuropsychological behavioural research with prosopagnosic individuals, and neuroimaging studies using fMRI techniques. In each case, we have asked what would happen if the hands were substituted for the eyes. We confirm that humans can haptically determine both identity and facial expressions of emotion in facial displays at levels well above chance. Clearly, face processing is a bimodal phenomenon. The processes and representations that underlie such patterns of behaviour are also considered.

Résumé Nous présentons un aperçu d'un nouveau programme de recherche pluridisciplinaire portant sur le traitement haptique de l'identité faciale chez l'humain et les expressions faciales de l'émotion, à partir d'une série d'expériences perceptives et neuroscientifiques avec des visages réels et/ou des masques tridimensionnels. Jusqu'à présent, plusieurs méthodologies convergentes ont été adoptées : études expérimentales du comportement sur des sujets neurologiquement intacts, recherche neuropsychologique du comportement sur des individus atteints de prosopagnosie et études en neuroimagerie au moyen de techniques d'IRM fonctionnelle. Dans chaque cas, nous nous sommes demandés ce qui arriverait si les yeux se substituaient aux mains. Nous confirmons que les humains peuvent déterminer dans des affichages de visages, de manière haptique et à des niveaux bien supérieurs au hasard, aussi bien l'identité faciale et les expressions faciales des émotions. Le traitement des visages est manifestement un phénomène bimodal. Nous examinons également les processus et les représentations qui sous-tendent de tels schémas de comportement.

Visual face processing has strong evolutionary significance across many biological species because the face carries different categories of information that are 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, to such an extent that specific neural substrates (sometimes referred to as a face module) may be dedicated to it (e.g., Kanwisher, McDermott, & Chun, 1997). Several arguments have been used to support the uniqueness of face-processing skills: Face recognition is species-universal in humans yet also observed in other species, it emerges early in development, and it is performed by highly specialized cortical areas. Not surprisingly, almost all research that supports this perspective has focused on vision. The current paper, however, reveals that the haptic system is also capable of processing both facial identity and facial expressions of emotion.

Background: Haptic Recognition of Inanimate Objects by Touch

Our current work on haptic face processing logically derives from an earlier research program that focused on the haptic recognition of inanimate common objects (e.g., Lederman & Klatzky, 1998; Klatzky & Lederman, 2007). Contrary to both scientific and lay thinking at the time, our initial investigations showed that humans are highly skilled at haptically recognizing common objects (Klatzky, Lederman, & Metzger, 1985). We subsequently showed (Lederman & Klatzky, 1987, 1990) that observers systematically explore such objects by performing an ordered series of one or more stereotypical hand movement patterns ("exploratory procedures" or "EPs"). Each haptic EP varies in the relative breadth of information it can simultaneously provide about multiple object properties, the relative speed with which it is performed, and the property information that it most precisely describes (e.g., surface texture, shape, etc.).

This earlier work highlights important differences between visual and haptic processing that have consequences for the effectiveness with which each modality processes and represents objects and their properties. First, the cutaneous system is considerably less spatially acute than the visual system (Jones & Lederman, 2006). Second, while vision typically employs simultaneous processing, the haptic system more commonly extracts information about objects sequentially, with heavy demands on spatiotemporal integration and memory. Limited tactile spatial acuity, sequential sensory inputs, and the relative efficiency of various exploratory procedures collectively constrain the haptic observer's ability to effectively process geometric (e.g., shape, size), as opposed to material, properties (e.g., texture, compliance, and thermal conductivity).

Guided by what we had previously learned about the nature of haptic processing of inanimate common and unfamiliar objects, we next posed a somewhat unusual question. As a class of common objects that likewise offers potentially valuable geometric and material information, might live faces also be perceptually accessible by touch? In this article, we present the results of a multidisciplinary research program that has been guided by three converging methodologies: behavioural experimental studies with neurologically intact participants, neuropsychological behavioural research with prosopagnosic individuals, and neuroimaging studies using fMRI techniques. Our results clearly reveal that face processing is in fact a bimodal phenomenon that can involve haptic or visual processing.

Haptic Processing of Facial Identity

In 2002, Kilgour and Lederman established that people can haptically discriminate unfamiliar live faces and three-dimensional rigid facemasks. Neurologically intact university students performed a match-to-sample task. In the absence of any practice, they bimanually explored a live face, followed in turn by three additional live-face comparisons. Participants were required to select the face that matched the original. As evident in Figure 1 (filled bar), participants were about 80% correct, a level far above chance (33%). To our knowledge, such a result confirmed for the first time that humans are indeed capable of processing facial identity by hand. Amongst several other experimental conditions, we chose to assess the specific contribution of live material facial cues by presenting rigid three-dimensional facemasks of our original live-face exemplars using the same match-to-sample task. The fact that performance remained well above chance when there was no variation in material cues (Figure 1, open bar) confirms the primary importance of structural (geometric) information in this face-matching task. However, because performance significantly declined to 58%, we concluded that material cues serve as an important secondary source of sensory information for haptic processing of facial identity. Our successful facemask results have also been confirmed by Pietrini, et al. (2004) and by Casey and Newell (2005). In summary, humans are capable of differentiating live faces and three-dimensional facemasks in terms of personal identity, corresponding to what Rosch, Mervis, Gray, Johnson, & Boyes-Braem (1976) called the subordinate level of object classification. Presumably this ability arises from the distinguishing information provided by three-dimensional geometric features and, with live faces, from material differences as well.

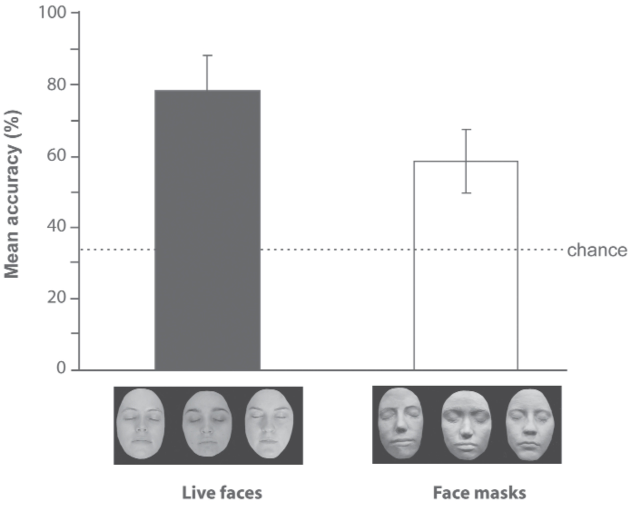

Figure 1. Face-matching accuracy for live faces (filled) and clay facemasks (open) (revised from Kilgour & Lederman, 2002, with permission of The Psychonomic Society).

The Haptic Face-Inversion Effect

In the visual face-processing field, a substantial body of research has revealed that faces are processed more accurately when they are presented in the normal upright position than when they are inverted (e.g., Yin, 1969). This highly reliable orientation-specific perceptual phenomenon is commonly referred to as the "face-inversion" effect. It has been suggested that inverting the face interferes with the observer's ability to configurally process faces relative to when they are upright. Similar impaired patterns of performance obtained with other methodologies that more directly interfere with configural processing (e.g., scrambling facial features,

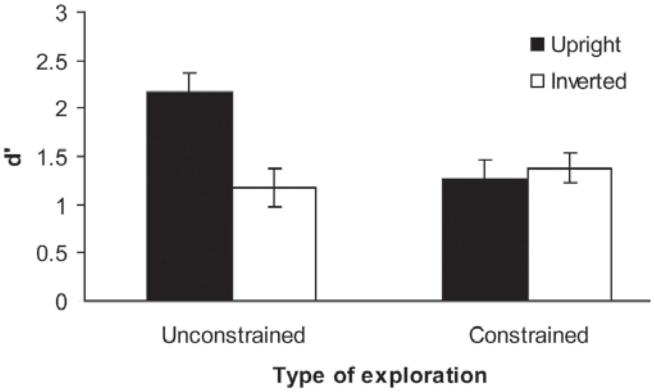

Figure 2. d´ (SEM) performance for upright versus inverted faces in temporally unconstrained (left side) versus temporally constrained (right side) exploration.

or morphing halves of different faces) have been offered as independent confirmation that the normal upright face is processed more in terms of the global configuration of its features than by the individual features themselves (e.g., Tanaka & Farah, 1993).

Until recently, the meaning of the term "configural processing" has proved somewhat elusive. Maurer, Le Grand, and Mondloch (2002) have helped to clarify the concept by offering a thoughtful analysis and discussion of the field. They note that at various times, the term "configural" has been used to describe: a) a sensitivity to first-order spatial relationships of the facial features (i.e., the eyes are above the nose, which is above the mouth), b) holistic processing or association of facial features into an overall Gestalt or whole, and c) a sensitivity to second-order relational information, such as the distance between designated features. The authors also highlight a number of behavioural and neural markers, differing developmental trajectories, and different responses to various experimental manipulations (e.g., rotation, negation) that serve to disambiguate the different forms of configural processing. Maurer et al. (2002) further note that inverting the face serves to disrupt all three forms of configural processing.

We asked whether there might be a haptic variant of the face-inversion effect. To address this issue, Kilgour and Lederman (2006) required neurologically intact young university students of both genders to make same/different judgments of pairs of three-dimensional clay facemasks. Pairs of masks were presented in orientation blocks that were either upright or inverted. The results presented in Figure 2 (left side) clearly show that, as with visual perception, observers were significantly better (in terms of d´) when the facemasks were upright than when they were inverted.

To date, we lack access to the technologies mentioned above (e.g., scrambling) that have permitted visual scientists to directly interfere with global configural processing. Thus it is not yet possible to conclude that the strong haptic inversion effect documented above is due to an interruption in global facial configural processing, to feature-based processing, or perhaps to something else.

We know of only two sets of studies that relate indirectly to the issue of configural- versus feature-based processing by the haptic system. First, our own previous research with hand-sized, multiattribute nonface objects (Lederman & Klatzky, 1990) suggests that haptic observers manually explore objects in two stages. Stage 1 consists of a whole-hand grasp in which the fingers mould to the object contours in an "enclosure" EP. Stage 2, which is not as consistently performed as Stage 1, involves the performance of one or more EPs, with EP selection guided by the property(ies) about which more precise information is sought. We note that the facemasks used in the Kilgour and Lederman experiment (2006) were larger than hand size. Hence, the haptic face representations must have been based on sequential haptic inputs. We wondered if, nevertheless, it was still possible that our observers emphasized global configural processing more when the faces were presented upright, and feature-based processing more when inversion interrupted global configural processing.

A second study by Lakatos and Marks (1999) offered a possible way of addressing the question we posed. They considered the relative extent to which haptic observers process local versus global object features. Participants were required to visually or haptically compare pairs of objects (other than faces) that differed in their local and global shape. Lakatos and Marks determined that early on in manual exploration, haptic processing was more feature-based; however, when sufficient time for haptic exploration was permitted, participants integrated the series of sequential inputs into a more fully global object representation.

Based on the results of the Lakatos and Marks study (1999), Kilgour and Lederman (2006) performed a subsidiary experiment in which haptic observers were permitted only 10 s exploration, sufficient for correct performance but far slower than the average 19-s response time observed during the first unconstrained-exploration experiment. In all other respects, the experiment was the same as the original. We reasoned that by reducing exploration time, the participants' ability to extract global information about the faces would be restricted, thereby forcing them to attend more to the local features of the face. We therefore predicted that the face-inversion effect would be eliminated or at the very least, much reduced. As evident in Figure 2 (right side), the results were in keeping with this prediction. There was no statistical effect of face orientation on d´ performance with the facemasks. Moreover, the mean d´ scores for the upright and inverted conditions in the constrained-exploration experiment were equivalent to performance in the inverted condition of the free-exploration experiment. It would appear that even with unlimited exploration, participants obtained no more information about the inverted faces than was available in the initial period of exploration with upright faces. Accordingly, the subsidiary results offer some support for the idea that upright facemasks may be processed more configurally; moreover, inverting the facemasks interferes with global configural processing, forcing participants to rely more on feature-based processing. As additional support for our suggestion, we noted that when participants with limited exploration time manually explored the inverted faces, they confined a good deal of the 10 s available to exploring the mouth and nose regions.

At this point, we believe it is not unreasonable to propose that our blindfolded observers may have relied on visual mediation inasmuch as faces are not objects that people typically classify, discriminate, and identify by hand. After all, humans are experts at processing faces visually. Accordingly, they may have adopted a strategy in which they converted the haptic inputs into a corresponding visual image, which they then reprocessed using visual mechanisms. For example, Lederman, Klatzky, Chataway, and Summers (1990) showed that when blindfolded sighted observers were required to haptically identify raised outline depictions of common objects, they chose to adopt visual imagery as a heuristic that improved recognition accuracy relative to a group of congenitally blind observers, who performed at chance level. If visual mediation was used as a heuristic when haptically processing faces, observers would process the upright faces configurally; however, because face inversion disrupts efficient visual configural processing, observers may have adopted a visual feature-based strategy, focusing more on selected features without regard to their overall spatial layout. At this point in our research program, we can clearly assert that haptic face processing of identity is orientation-specific, and have suggested how upright faces may be processed on the basis of their global configuration. Recent results by Casey and Newell (2007, Experiment 3) have further shown that configural information is shared between touch and vision. Participants were presented with a haptic face, followed by an intact, scrambled, or blurred visual facial image, depending on the experimental block. A same/different judgment was required. Intact and blurred (configural information preserved) conditions were not significantly different from one another and yielded faster response times than the scrambled condition (configural information not preserved). These results suggest that to the extent that touch and vision do share information, configural face representations enhance cross-modal face matching; however, the results do not directly speak to whether impaired configural processing specifically underlies the haptic inversion effect we have documented.

Neuropsychology and Prosopagnosia

Prosopagnosia is a disorder in which individuals have difficulty visually differentiating specific faces at the subordinate level, although they remain capable of classifying such objects as a “face” at the basic level (Rosch et al., 1976). The face-inversion effect has played an important role in understanding the nature of the visual processing deficits that underlie prosopagnosia. While some of these individuals do not demonstrate the usual face-inversion effect, others demonstrate a “paradoxical inversion effect” in which inverted faces are actually processed better than upright faces (e.g., de Gelder & Rouw, 2000; Farah, Wilson, Drain, & Tanaka, 1998).

Cases of cross-modal influence and association have been documented since the advent of psychological science and many of these known instances have been reviewed by Welch & Warren (1986) and most recently by Calvert, Stein, and Spence (2004). Accordingly, Kilgour, de Gelder, & Lederman (2004) were curious to learn whether a 50-year-old male with prosopagnosia (LH) who was unable to differentiate faces visually would fail to differentiate them haptically. As LH’s sensorimotor hand function was not previously known, we began by performing several relevant tests. LH showed normal cutaneous performance (pressure; two-point touch thresholds), normal accuracy for fine motor control (Grooved Pegboard) albeit somewhat slower than normal, and normal accuracy for haptic recognition of common objects. We concluded that LH had relatively normal sensorimotor hand function.

We then required LH to perform the same/different face-inversion task that we used with neurologically intact university students (Kilgour & Lederman, 2006). In addition, we ran a small group of neurologically intact control participants matched to LH in terms of age, gender, and education. The accuracy and response time results for LH and the control group are shown in Figure 3 (Panels A and B, respectively). Overall, LH differentiated face pairs very poorly: Relative to the control subjects, LH was both highly inaccurate and considerably slower. To our knowledge, these data constitute

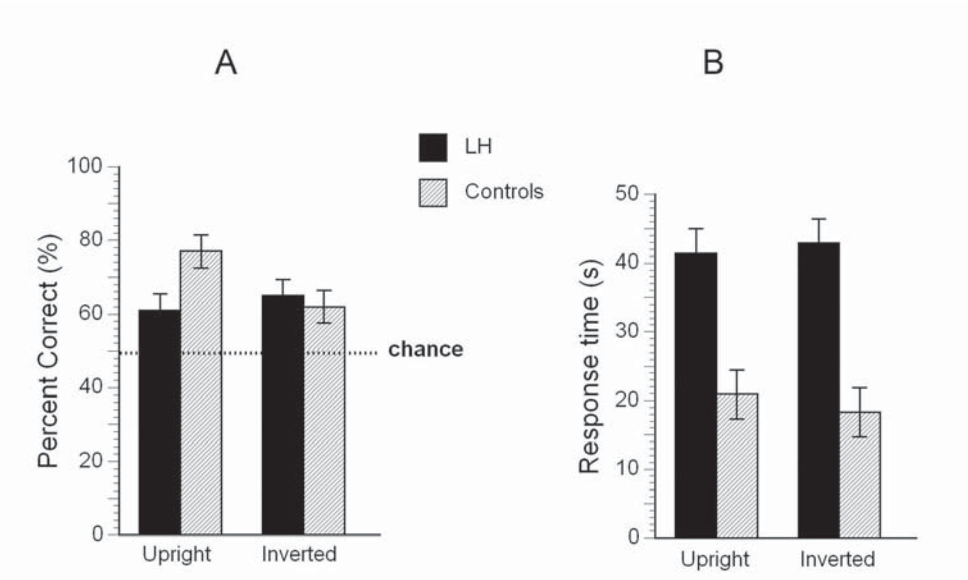

Figure 3. Panel A: Accuracy for upright versus inverted facemasks by a prosopagnosic individual (LH) versus matched controls; Panel B: Corresponding response times. (Reprinted from Kilgour, de Gelder, & Lederman, 2004, with permission of Elsevier.)

the first reported case of "haptic prosopagnosia." Although LH's performance in the upright condition was not statistically different from that in the inverted condition, only the latter was statistically better than chance. This reversed pattern of response could be described as a "paradoxical inversion" effect, and occurred when LH was tested both haptically and visually. In contrast to LH's performance, the control subjects demonstrated a clear haptic inversion effect, much like the younger university participants (Kilgour & Lederman, 2006). Much additional research is required to understand the nature of the underlying haptic processes and associated neural mechanisms that subserve this intriguing failure in haptic face processing, as well as the implications for normal face perception.

Neural Mechanisms of Haptic Processing of Facial Identity

An important issue for neuroscientists relates to the brain areas that participate in face recognition regardless of input modality. Research has confirmed that a particular area in the right fusiform gyrus, known as the Fusiform Face Area (or FFA), is dedicated to visual face identification (e.g., Kanwisher, McDermott & Chun, 1997). However, until very recently, very little has been known about the neural correlates of haptic face recognition. Accordingly, we have begun to use functional magnetic resonance imaging (fMRI) as a methodological tool for examining brain activation during haptic processing of facial identity.

Three sets of data guided our initial prediction. The first related to the study by Kilgour et al. (2004) that documented a substantial deficit in haptic face differentiation by LH, the individual who sustained several cortical and subcortical lesions, including the right temporal lobe (Etcoff, Freeman, & Cave, 1991; (e.g., hippocampus, left subcortical occipitotemporal white matter, and bilateral parietooccipital regions). A second complementary set of studies included the haptic recognition of three-dimensional common objects, nonsense shapes and in one study, lifelike facemasks by neurologically intact participants (e.g., Amedi, Jacobson, Hendler, Malach, & Zohary, 2002; Deibert, Kraut, Kremen, & Hart, 1999; James et al., 2002; Pietrini et al., 2004; Reed, Shoham, & Halgren, 2004). Collectively, these studies implicated the involvement of ventral occipital and temporal cortex in the haptic recognition of familiar and unfamiliar three-dimensional objects relative to baseline (i.e., with texture or rest as control). The tasks typically required classification at the "basic" level, such as pencil or cup (Rosch et al., 1976). A third set of studies specifically addressed the underlying neural region(s) involved in face processing. As mentioned above, visual studies have implicated the FFA region of the fusiform gyrus. However, the study by Pietrini et al. (2004) suggested that the haptic and visual face-specific neural response patterns do not overlap within the fusiform gyrus, thereby calling into question the existence of a small multisensory, face-specific processing region. Nevertheless, it remains possible that the right fusiform gyrus mediates face recognition as a whole, but that different subregions

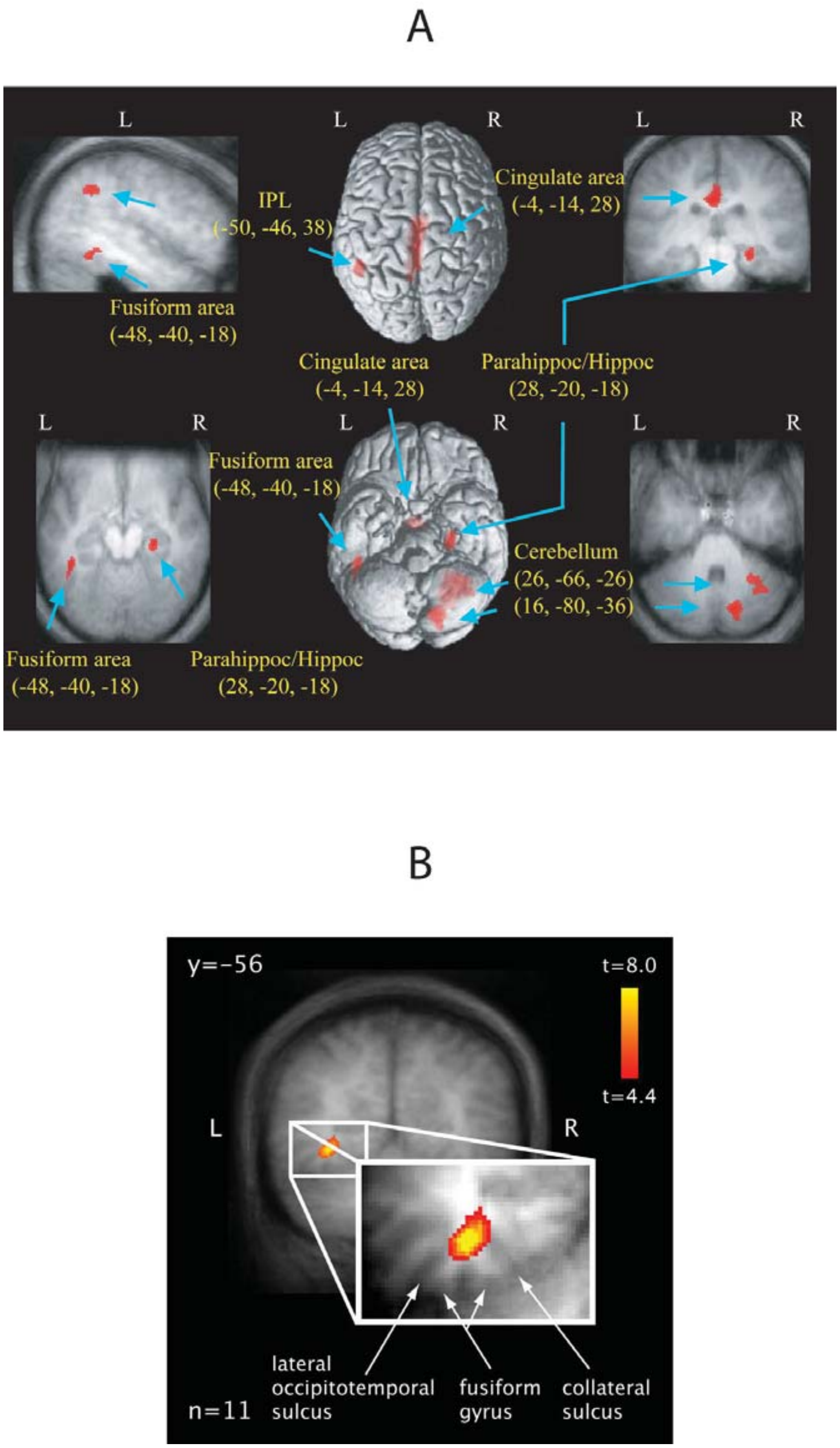

Figure 4. Activation of the left fusiform gyrus by haptic face recognition. Panel A: A functional brain map that compared identification of facemasks and sensorimotor control objects. L = left; R = right (reprinted from Kilgour et al., 2005, with permission from Elsevier); Panel B: A functional brain that compared recognition of familiar and unfamiliar facemasks. (Reprinted from James et al., 2006, with permission of Elsevier.)

are activated by normal vision and haptics. Based on these three sets of neural studies, Kilgour, Kitada, Servos, James, and Lederman (2005) predicted that ventral occipital and temporal regions of the brain may also play a significant role in the haptic identification of three-dimensional facemasks by neurologically intact participants.

Kilgour et al. (2005) extensively trained right-handed blindfolded individuals to haptically identify by name a selection of 18 of the three-dimensional rigid facemasks used by Kilgour and Lederman (2002, 2006) and another 18 three-dimensional sensorimotor control objects. The left hand/right hemisphere was used both because it may have a small advantage over the right hand/left hemisphere in haptic spatial tasks (Summers & Lederman, 1990) and because it may increase the chances of obtaining right-hemisphere activation (e.g., Kolb & Whishaw, 2003). The behavioural studies with neurologically intact and prosopagnosic participants that were previously described used either a perceptual matching or a discrimination task, both of which may have elicited a relatively low level of specificity in the face representation with respect to facial identity. To obtain a higher level of face specificity during the face representation process, we chose a face-identification task here to encourage participants to process the facemask stimuli explicitly as "faces." Training lasted anywhere from 10-12 hours/participant until each person could recognize the stimulus objects with 100% accuracy within about 7-8 s, on average. The facemasks and control objects were of comparable difficulty and elicited similar patterns of manual exploration.

After criterion-level performance was attained, participants were placed in a 4-T magnetic chamber while they manually explored subsets of the highly learned facemasks and control objects (n = 12/subset), again using their left hands. In the formal experiment, subjects silently named each stimulus object. Based on our specific prediction, we focused on the posterior portion of the brain from central sulcus to occipital pole. In this initial stage of our neural investigation, we did not attempt to separate haptic face processing from memory processes, which we assume are an important component of haptic face identification.

Haptic identification of the facemasks significantly activated left fusiform and right hippocampal/parahippocampal regions, thus supporting our hypothesis that ventral temporal and occipital areas of the brain would be involved. In addition, left cingulate gyrus, left inferior parietal lobe, and right cerebellar regions were also more strongly activated by faces than by sensorimotor control objects matched for difficulty, familiarity, and manual exploration. No additional areas were activated by the control objects beyond those activated by the facemasks.

Although our results confirm the involvement of the fusiform gyrus in haptic face identification, the left (not the right) hemisphere was more strongly activated, as shown in Figure 4A. This occurred despite manual exploration by the left hand and the more commonly noted small advantage of the right hemisphere in haptic spatial tasks. It is possible that in comparison to vision, which can process facial features simultaneously, haptics, which demands integrating information typically extracted sequentially during manual face exploration, might have resulted in greater left-hemisphere activation. Alternately, left-hemisphere fusiform activation might be the consequence of our subjects adopting a visual image-mediation heuristic to haptically identify faces (see e.g., Lederman et al., 1990). In keeping with this suggestion, visual imagery of faces has been shown to elicit greater activation in the left ventral temporal cortex (e.g., Ishai, Ungerleider, & Haxby, 2000). These possibilities will be more directly addressed in future work.

At this point, however, we may conclude that ventral occipital and medial temporal regions may play an important role in the neural network that subserves haptic face identification. In conjunction with the earlier haptic fMRI findings described above, we suggest that these areas constitute part of a neural network that mediates haptic processing of common (both face and nonface) objects and nonsense shapes at both basic and subordinate levels (Rosch et al., 1976).

James, Servos, Huh, Kilgour, and Lederman (2006) subsequently extended the Kilgour et al. (2005) study to specifically address the contribution of familiarity to haptic face identification. As in the previous study, participants were initially trained extensively to identify a subset of the clay facemasks used in the previous study with their left hand ("familiar"). Once they had attained the mandatory high level of performance, they were presented with a subset of the familiar facemasks and another subset containing an equal number of facemasks that had not been previously explored ("unfamiliar"). Using their left hand, participants were required to indicate whether each face was familiar or unfamiliar. Previous research has shown that neural responses in LOC (Lateral Occipital Complex) are most typically increased by previous haptic or visual experience when objects are subsequently viewed again (e.g., James et al, 2002; Jiang, Haxby, Martin, Ungerleider, & Parasuraman, 2000). Figure 4B presents a functional map of the brain that contrasted familiar and unfamiliar facemasks. Based on our predefined threshold criterion, only a single cluster produced a significant difference in activation. As in Kilgour et al. (2005), the left fusiform gyrus was activated more strongly than the

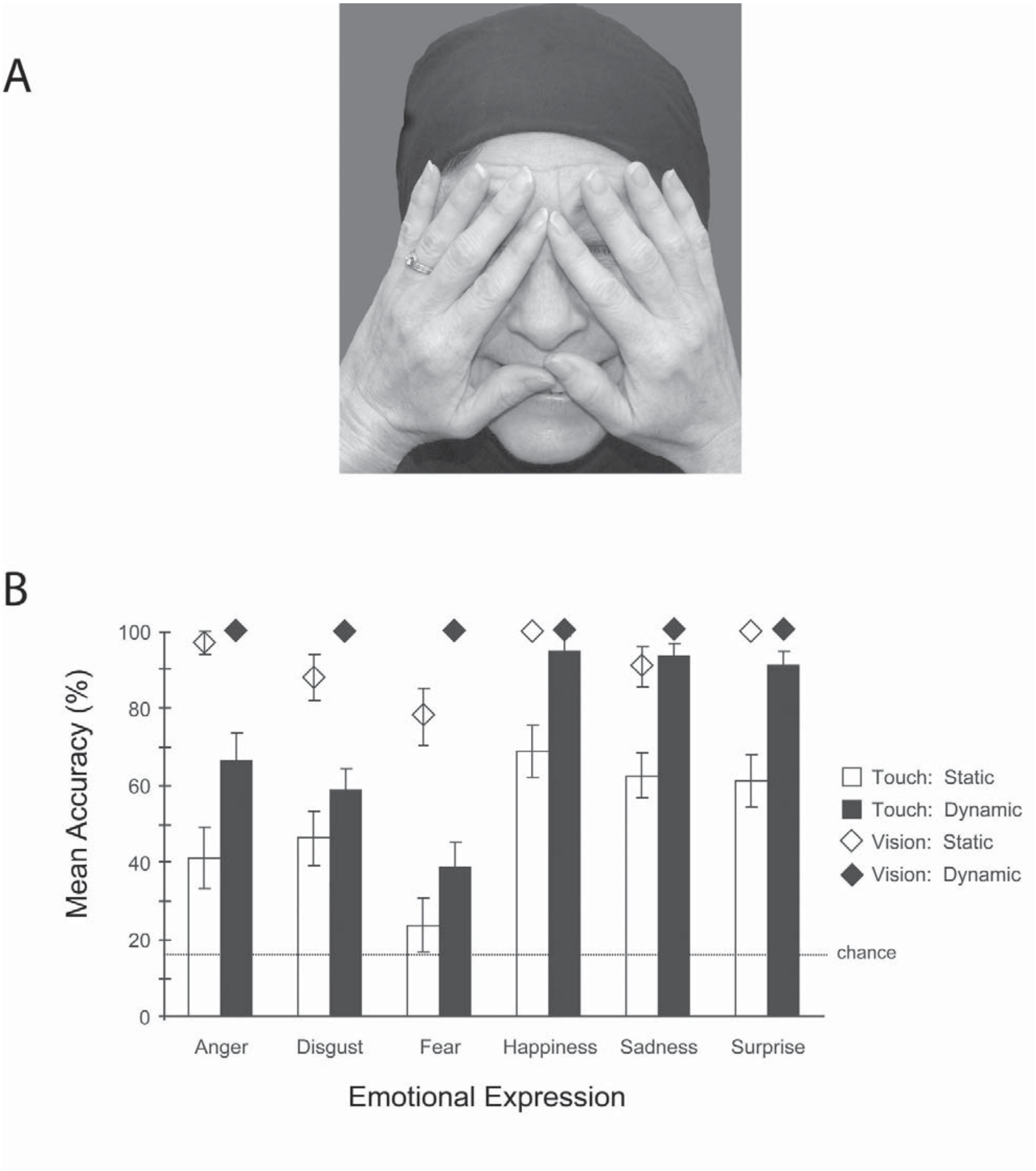

Figure 5. Panel A: Static "happy" expression portrayed by live actress showing starting position of the participant's hands. (Reprinted from Lederman et al., 2007, with permission of Blackwell Publishing.) Panel B: Haptic identification accuracy for six facial expressions of emotion. Open bars: Static displays; filled bars: Dynamic displays. Visual control data are shown by open (static) and filled (dynamic) diamond symbols. (Reprinted from Lederman et al., 2007, with permission of Blackwell Publishing.)

right, despite the fact that using the left hand should have favoured greater right-hemisphere activation. The current study indicates that left-hemisphere activation in the fusiform gyrus specifically differentiates between haptically familiar and unfamiliar faces.

There are several intriguing explanations for this left-hemisphere dominance that deserve careful future consideration. First, participants may have adopted a visual-mediation strategy, in keeping with our suggestion regarding our previous fMRI study (Kilgour et al., 2005). Second, differences in the way the sensory information is input through vision and haptics may have processing consequences. Typically, with vision, people may adopt a fast and spatially holistic processing heuristic with upright faces. In contrast, with haptics, they must typically input facial features sequentially and then integrate this information over time. Separating spatial and temporal integration into right and left hemisphere dominant functions is strongly supported by research on cerebral lateralization (Kolb & Whishaw, 2003). A third alternative highlights the considerable amount of haptic training our participants received. Some vision researchers have argued that the right fusiform face area may be activated more generally when observers are "experts," whether the object class involves faces, some nonface objects, or even novel objects known as "Greebles" (Gauthier, Skudlarski, Gore, & Anderson, 2000). In keeping with this interpretation, it is possible that the left fusiform gyrus is more strongly activated by haptic expertise for any object class, including faces and regardless of visual face expertise.

Haptic Processing of Facial Expressions of Emotion (FEEs)

Humans are also capable of communicating their emotions, both verbally and nonverbally, by varying their facial expressions (Darwin 1872/1955). Facial expressions of emotion may be regarded as the converse of facial identity in that the invariant features of each emotion are applied *across*, as opposed to within, faces. The invariants of each facial expression are derived from both the stationary skeletomuscular patterns within the face and from the transient changes in these patterns over time. Across cultures, humans can successfully recognize a small set of facial expressions of emotion that include anger, disgust, fear, happiness, sadness, and surprise. Ekman and Friesen (1975) have detailed these expressions in terms of specific "Facial Action Patterns" that have visually detectable consequences that are used to process facial expressions of emotion in still photographs, line drawings, and artificial dynamic displays.

Most recently, we have considered whether people are also capable of *haptically* identifying expressions of emotion in the live face. This question seemed reasonable to us inasmuch as the invariant features of the skeletomuscular facial displays of each emotion are potentially accessible through the hands, as well as the eyes. Accordingly, Lederman et al. (2007) presented live-face displays of the six universal facial expressions of emotion to both hands of the participants. In one experiment, the displays were all statically presented, as shown for "happy" in Figure 5A.

On each trial, two trained actresses initially produced the targeted facial expression, and then held it. The experimenter then arranged the participant's hands across the actress' face as shown in Figure 5A. The participant was then free to haptically explore the face until he or she had identified the emotion as quickly and accurately as possible from six possible choices. In a separate experiment, the facial expressions of emotion were formed and dissolved dynamically as many as four times beneath the participant's static hands. Only one of the actresses was used this time because the results obtained with each actress in the first experiment were very similar.

With the exception of statically expressed fear, our untrained participants were able to tactually identify all facial expressions of emotion at levels well above chance (17%). Figure 5B shows percent accuracy for the static (open bars) and dynamic (solid bars) displays for each emotion. Averaged across expressions, the mean accuracy was 51% and 74% for static and dynamic displays, respectively. The dynamic versions of the emotional expressions were clearly identified more accurately than the static versions. In addition, performance clustered into two subsets of emotional expressions, a relatively low-performance group consisting of anger, disgust, and fear, and a relatively high-performance group consisting of happiness, sadness, and surprise. Based on the corresponding stimulus-response confusion matrices, members of the low-accuracy group were broadly confused, both with each other and with members of the high-accuracy group. The converse was not the case; that is, there were very few errors within the latter cluster, and little confusion with members of the former cluster. We propose that performance may reflect relative differences in feature distinctiveness, which in turn may be influenced by several possible factors: One or more facial regions uniquely describe an emotion (e.g., cheeks for happy); despite shared region(s), there is a qualitative difference (e.g., lips curve up, down or are level) and/or a quantitative difference (lips closed, slightly open, wide open). Corresponding data from two visual control conditions were also obtained from a small number of participants. These are shown in Figure 5B as open (static) and filled (dynamic) diamond symbols. It is particularly

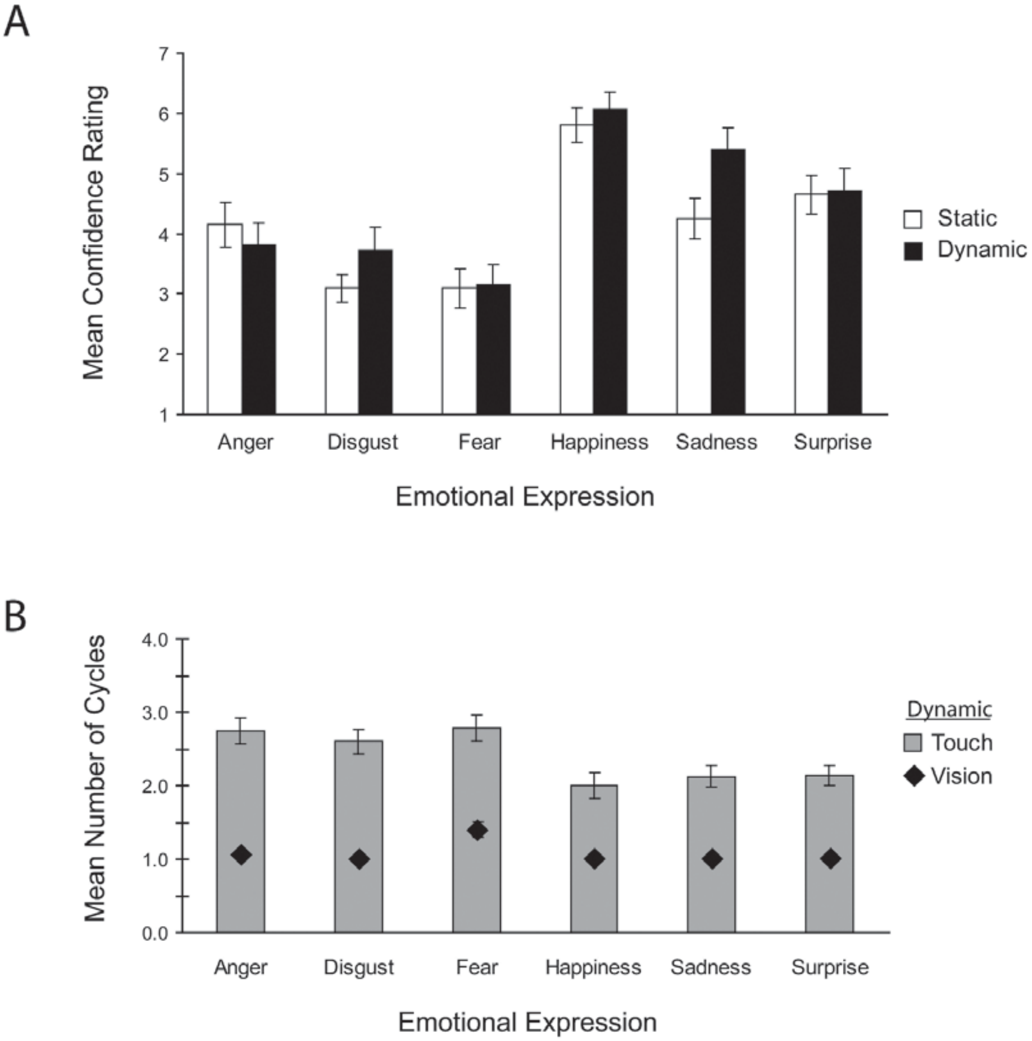

Figure 6. Panel A: Haptic identification confidence ratings for six facial expressions of emotion. Open bars: Static; filled bars: Dynamic (reprinted from Lederman et al., 2007, with permission of Blackwell Publishing); Panel B: Corresponding mean number of dynamic cycles (max = 4). Grey bars = touch; filled diamonds = vision control.

impressive that with minimal training, the high-performance haptic group performed close to the 100% level attained by the visual group when observing dynamically expressed emotion.

A similar overall picture emerges from confidence ratings obtained at the end of the experiment, as shown in Figure 6A. As collecting precise response times was not possible when running such demanding experiments, we chose to record instead the number of dynamic cycles in which the emotion was formed and dissolved (max = 4 cycles). Figure 6B also reveals the same two clusters of emotion, with fear requiring the most number of cycles. For purposes of coarsely comparing the overall duration in the dynamic and static conditions, we converted the overall mean number of dynamic cycles (2.4) to seconds (1 cycle = ~ 2 s), and compared this value to the 9-s mean estimate of overall static duration based on available videotape data.

Collectively, the results of this study confirm that with minimal training, our participants were clearly capable of identifying facial expressions at levels typically well above chance. Moreover, they were more accurate, faster, and more confident identifying the dynamic than the static facial displays of emotion.

The nature of the processes used to identify emotional facial expressions is important to determine. Calder, Young, Keane, and Dean (2000) have shown that the visual recognition of facial expressions of emotion was impaired when faces were presented in the inverted orientation, confirming that configural (vs. featural) processing is important to vision. Results from a study we have only just completed reveal a small haptic inversion effect for emotional expressions. Collectively, these new results speak to the nature of the process(es) and representations during haptic facial recognition of emotions, and to whether the underlying processing and face representations are similar to those produced by the visual system.

Summary and Conclusions

The research reported in this paper has revealed that with little or no training, humans are capable of haptically processing the facial identity of both live faces and facemasks and the common facial expressions of emotion at levels well above chance. Like Tadoma, the tactile method used successfully by a very small number of deaf-blind to monitor speech, our work confirms that manual contact with the face constitutes a highly informative input channel (Reed et al., 1985). However, unlike proficiency with Tadoma, haptic face recognition is not limited to just a few trained users. Clearly, face processing is not unique to vision. Our future research will be directed toward better understanding the nature of the haptic face processes used to identity individual faces and their expressions of emotion, the neural circuitry that mediates these functions, and finally, the similarities and differences in the corresponding visual face-processing conditions.

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