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The Neuropsychology of Lipreading [and Discussion]

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The neuropsychology of lipreading

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SUMMARY

Lipreading presents a unique glimpse of the intersection of sensory processes with modular, cognitive ones. It presents speech to the eye in an automatic and natural way, whether performed silently or in conjunction with heard speech. It therefore allows us to examine closely claims concerning the relation between input modality and cognitive function. In this paper I consider some of the ways in which the investigation of single neuropsychological cases casts light on this; such cases show us that lipreading can dissociate from other aspects of face perception and recognition, and from auditory speech perception and reading, too. Furthermore, different cognitive components of lipreading itself can be inferred from dissociations on different lipreading tasks. This leads to closer consideration of the boundaries of the necessary cognitive (and possibly anatomical) structures that subserve these functions.

1. INTRODUCTION

Summerfield (this symposium) cogently outlines the ways in which lipreading is useful to sighted speakers of the language. Among those I would highlight the following: (i) the ability to detect lip-speech correspondence is evident from early infancy, both for synchronization of speech (Dodd 1979) and for the correspondence between lip shape and vowel sound (Kuhl & Meltzoff 1982, 1984); and (ii) seeing the speaker can not only improve auditory speech comprehension in noise (Miller & Nicely 1955) but can also change the perception of the speech sound. The first demonstration of this was the auditory-visual fusion illusion (McGurk & MacDonald 1976; Massaro 1987) where a seen 'ga' and a heard 'ba' seemingly combine to give the impression that 'da' was spoken. There are allied effects where seen phonetic gestures (speed and shape of lip movements) can shift the boundary of categorization of synthetic speech sounds (see, for example, Green & Miller 1985; Green & Kuhl 1989, 1991). When we watch someone speaking we are lipreading, at least for the purposes of this chapter. All these demonstrations have been made on normal hearing people and report little individual variation in skill or susceptibility. We make fluent and effective use of seen speech under certain conditions and cannot avoid making use of the modality we may be instructed to ignore when heard and seen inputs coincide.

Lipreading is a natural ability, albeit of dubious utility. This point is underlined by failures to find good correlations between lipreading and other cognitive tasks (Summerfield 1991). Why should it interest the psychologist or the neuropsychologist? One answer is that a number of theoretical approaches to cognitive function stress that the modility of input is critical to the acquisition of a particular ability. This input imperative is evident in formulations that seemingly stress a different notion, namely that cognitive functions are organized as discrete, independent modules (see, for example, Fodor 1983). If the modality of input determines modular function then it is particularly important to examine how lipreading fits in the scheme of things, for lipreading is a natural way of seeing speech rather than hearing it or learning to read it through many years of schooling and training. Will we find, for example, that lipreading associates with left or right hemisphere function; does it develop with visual skills, especially faces, in the right hemisphere, or with language skills, including listening, speaking (and secondarily, reading) in the left hemisphere?

Two studies done several years ago posed this question directly. The first (Campbell 1986) showed that, for normal right-handed university students, the task of matching a unilaterally tachistoscopically presented face photograph to a heard speech sound was better performed by the right than the left hemisphere. This suggested that the face-processing speciality of the right hemisphere was actively involved in lipreading. However, quite a different result came from a study of two neuropsychological patients (Campbell *et al.* 1986). These patients had, respectively, a left and a right temporo-parieto-occipital lesion. The patient, Mrs T., was typical of those with lesions in the left temporo-occipital region in showing spared spoken language and language comprehension, but profound reading difficulty. She knew which letters should be in which words (she could spell words correctly) but was unable to map this knowledge to the letters on the page in front of her (pure alexia). Yet she did not have any apparent visual deficit, for her ability to name all sorts of other material, including faces, objects and symbols such as road signs and flags, was perfect. By contrast, Mrs D., the patient

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Table 1. *Tests of lipreading accuracy*

live action test	Mrs D. (prosopagnosia, RH damage)	Mrs T. (alexia, LH damage)
confrontation with the speaker who 'lip-speaks' to the subject		
single digits for oral repetition (6 items)	normal	normal
pairs of digits for oral repetition (6 items)	normal	normal
point vowels 'u', 'i', 'a' (10 items)	normal	normal
consonants 'bi', 'vi', 'shi', 'thi' (10 items)	normal	a few errors
tests with high contrast face photographs (4 individuals, 3 views, 3 sizes)		
sorting 60 photographs into two piles: speaking faces and faces that are 'gurning'	normal	poor
sorting the 'speaking faces' by speech sound	normal	poor
identifying the speech sound	normal	poor
McGurk effect		
see 'ga' + hear 'ba' = reported 'da' (25 syllables)	normal	only heard channel reported

with a lesion in the corresponding areas of the right hemisphere, could read well. Like Mrs T., her auditory speech comprehension and production were unaffected by the stroke. But Mrs D. could not recognize faces of people who should have been familiar to her, and could not name pictures of famous people. She was prosopagnosic. Furthermore, she was poor at reading expression from faces. For instance, she was uncertain in indicating whether the lower half face in a photograph was smiling or frowning.

Which of these patients might be expected to show an impairment in reading speech from faces? Table 1 shows the types of test we did, and the results for each patient. Contrary to what might have been expected from the study on face-photograph/speech-sound matching in normal people, the patient who could not lipread normally was the one with the left hemisphere lesion, Mrs T., who had no other face-processing problem. Mrs D., although she was unable to identify any of the faces seen in the lipreading tests, and was unable reliably to discriminate a photographed smile from a frown, was nevertheless able to match faces on the basis of what speech sound they were making, and was able to do this across different facial identities and viewpoints. Mrs D., not Mrs T., was susceptible to the McGurk fusion illusion.

These patients demonstrate double dissociation of function. That is, these findings suggest that processing photographed faces for identity and expression judgement, and reading speech from faces, may use different 'cognitive modules.' Prosopagnosia and agnosia for facial expressions can coexist with normal lipreading and susceptibility to lip–speech illusions. Lipreading impairments can be demonstrated in a patient with no other apparent face-processing problems. The principled use of lipreading as a conceptual knife has made a first cut into cognitive space. Whereas the right hemisphere may be specialized for 'visual things', and may come into its own in judging briefly displayed face photographs (Campbell 1986), its role may not be critical in reading speech from faces. It appears that some parts of the left hemisphere seem to be needed for effective extraction of 'visual speech' as well as for auditory speech. In connection with this, it looks as if the reading processes that are disturbed in Mrs T. might even be used for lipreading. A classical explanation (Geschwind 1965) for her reading difficulty is that the near-midline position of the lesion blocks visual inputs from both occipital lobes, which can no longer access a 'visual word form' centre in the posterior left hemisphere.

2. READING, HEARING AND LIPREADING

Once a double dissociation has been demonstrated it is tempting to seek more. Are lipreading and reading related in anatomical and functional neuropsychological terms as Mrs T.'s deficits might suggest? If these skills doubly dissociate then that would suggest that different types of visual input processed in a linguistic fashion can be differentially lesioned and functionally separated. There is some evidence that these skills can doubly dissociate. M. Regard (personal communication) has reported a patient who resembles Mrs T. in having a left temporo-occipital lesion and pure alexia, yet who was able to lipread. Moreover, case A.B., who is described in more detail later in this paper, is an excellent reader, but her lipreading is abnormal. As spared lipreading may co-exist with pure alexia, and impaired lipreading with excellent reading, there is some separability of process for these two functions. However, the extent of this separation is still not clear; confirmatory evidence for dissociability may need firmer foundations.†

† An unpublished study by A. W. Young, B. Flude and A. W. Ellis suggests that lipreading and reading may sometimes interact. They asked subjects to categorize from photographed lip shapes the point vowels 'i' and 'u' from which a 'speech bubble' was seen with a written word on it. When the written word was spelled in a regular fashion ('been') it interfered with the categorization of the lip pattern if that was dissimilar. The interference did not occur when the written word used an ambiguous spelling of the vowel sound ('beach'), suggesting that seen lips and seen letters may share some common processing in deriving simple, regular speech sounds from a visual symbol.

What of lipreading and hearing? If the speech module really is driven and determined by the modality of input then it might be predicted that lipreading and hearing utilize different cognitive systems; that lipreading enjoys a 'special route'. Most of the evidence, not least from audio-visual speech illusions, suggests that lipreading and auditory speech processing do use a common metric which is phonetical (although supramodal) in nature (see Summerfield, this symposium). I have claimed elsewhere (Campbell 1990) that a common phonetic resource for seen and heard inputs makes most sense of what we know of the short-term memory function for lipread and heard material. In turn, this suggests that lipreading will be useful to an aphasic patient only to the extent that a central amodal phonetic processor is undamaged, and that output from such a processor suffers no further impairment. Some patients with cortical word-deafness might illuminate this. These are patients who, following cerebral insult, can no longer process heard speech despite intact hearing (they can identify environmental, including musical, sounds). Such patients should (and do) resemble patients with more peripheral acquired deafness. In intact lipreading, although auditory access to the phonological processor may be ineffective, the processor itself is still working and can use seen lip movements. By contrast, patients who have damage to the phonological processor or who have impaired auditory lexical access or poor repetition from audition may not improve for lipreading, for both lexical decision and repetition are assumed to rely on intact phonological processing: several patients also fit this account (see Campbell 1990).

3. VISUAL SUB-PROCESSES IN LIPREADING

What are the visual components and correlates of lipreading? I have already suggested that neurological evidence shows us that lipreading can dissociate both from reading and from other processes that use the face. To gain further insight into this question we may investigate individuals who show a range of impaired and spared skills in the visual domain generally. The first is A.B. (For a fuller report see MacConachie (1976); de Haan & Campbell (1992).) She is a professional young women who, as far as we know, has never had any cerebral trauma, but who has never been able to recognize faces. Her impairment is so profound that she fails to recognize family members, close friends and daily colleagues by sight, although her recognition of individuals by voice is good. She is developmentally prosopagnosic. On low contrast CT scan in 1980 there was no indication of abnormal cerebral development. In addition to face recognition impairment, A.B. is poor at discriminating facial expressions from photographs and is unable to discriminate the direction of eye gaze in photographs (Campbell *et al.* 1990*a*). A.B. shows an abnormal pattern of lipreading on all tests. She cannot reliably sort mouth shape from face photographs into speech and non-speech categories, and makes occasional errors of misidentification of speech pictures (such as mistaking an 'oo' face for one saying 'mm'). Her sorting is also very slow. When first tested in 1988, she seemed to be not susceptible to the McGurk fusion illusion for seen and heard stop consonants. She always reported the sounds that she heard and not the fused or seen percept (Campbell *et al.* 1990*b*), although more recent testing suggests greater variability. A.B.'s lipreading is abnormal in other ways, too. For instance, she could not detect lexical stress in faces seen to be speaking sentences with the word stress in different positions, whereas control subjects were able to do this easily. A.B. has no visual problem in the general sense; she learned to read early and well, and is fast and very accurate at recognizing letters even when they are deformed by shadow or orientation. She can unpack line drawings of overlapping and embedded figures into their constituents. But she is not perfect at recognizing objects from unfamiliar viewpoints, and sometimes makes mistakes in identifying photographs or drawings of objects, although her mistakes are of objects roughly similar in appearance to the target (i.e. guitar misidentified as violin). We argue (Campbell & de Haan 1992) that A.B. has underspecified structural encoding for visually presented objects, and that this is particularly deleterious for face identification. Because A.B. has impaired visual processing for all aspects of tasks that require faces to be discriminated we conclude that there is indeed a common level of visual form perception that supports natural lipreading just as much as other face processing tasks, and that this level is not required for reading script or type. The critical aspects of this level of representation might, for instance, involve the ability to extract a figure from intensity values (tone) that change with orientation and illumination, or that might have a three-dimensional character not required for letter reading. Another possibility (Farah 1990) is that this level of visual processing is essentially non-componential: it engages a system of representation where the configuration as a whole is processed, rather than its features or parts. Thus Mrs D. cannot recognize faces or facial expression (they rely on such non-decomposable, non-componential processes), although she can lipread (a componential process, using just part of the face). This interpretation is less plausible in the case of A.B.; arguably in reading speech from the face it is not necessary to identify the face as a whole, but only to make sense of what the lips are doing. This A.B. cannot do well, although her reading is excellent. Nevertheless, although face identification skill was almost completely absent, A.B.'s problems with identifying facial expression and lip-speech photographs were not so profound, although they were markedly abnormal.

Both Mrs D. and A.B. were unable to recognize faces and were poor at identifying facial expression. Mrs D. could lipread but A.B. was poor at lipreading. So here is further fractionation of face processing, and an indication that there is a level of visual analysis that is necessary to support lipreading which can be separated from other visual processes. A further case of visual agnosia adds yet another twist to the story.

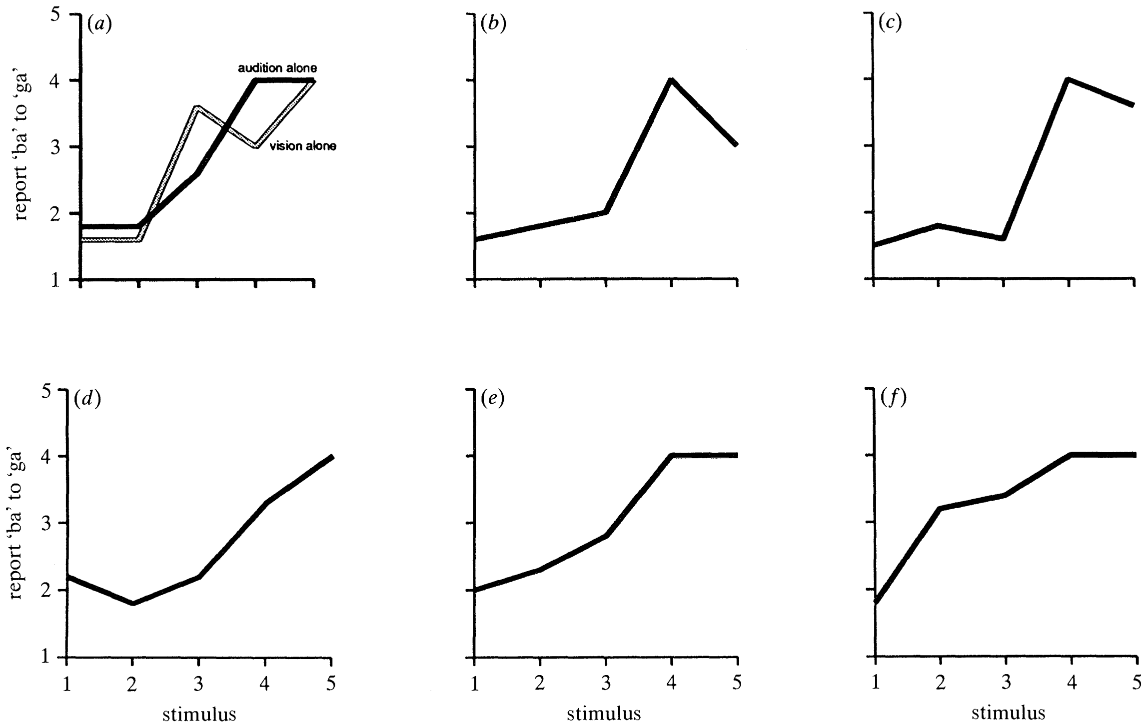

Figure 1. H.J.A.'s performance on Massaro's (1990) tests of perception of synthesized, synchronized tokens of seen and heard speech. (*a*) Single modality; (*b*–*f*) audition with vision (1)–(5), respectively.

4. MOVING AND STILL LIPS: FURTHER DISSOCIATIONS

H.J.A. is a well-studied case of visual agnosia (Humphreys & Riddoch 1987). He had a bilateral occipital stroke in 1981, extending anteriorly to the inferior temporal cortex. Humphreys & Riddoch characterize his perceptual agnosia as a functional difficulty in perceptual parsing. His visual skills appear to be particularly compromised when he has to discriminate salient from non-salient parts of a seen form, and in relating descriptions of wholes to parts of seen objects. Naturally, this perceptual agnosia extends to faces, and H.J.A. is very impaired at all tasks concerned with face processing (Donnelly *et al.* 1990). However, H.J.A. can correctly identify facial expression and gender from a face in movement. We therefore asked whether H.J.A. may show dissociated skills in lipreading: perhaps he could not process still pictures of lip actions but could infer lip speech from moving stimuli?

When given the tests described earlier, H.J.A. was unable to identify still pictures of lipspeech. In fact, he was much worse than A.B. who could sometimes, slowly, manage the sorting task. However, H.J.A. was sensitive to seen lips in movement. Massaro (1990) has devised a videotape comprising five different (synthetic) faces seen to be speaking sounds from 'ba' to 'da' through intermediate, synthesized tokens synchronized with five auditory tokens of 'ba' through 'da'. The videotape also contains silent (vision alone) and heard (no vision) stimuli. The subject reports what he believes was said from a range of possible syllables. Stimulus values and reported stimuli range from 'ba', categorized as (1), to 'ga', categorized as (5), through intermediate utterances like 'va' (2), 'tha' (3) and 'da' (4).

H.J.A.'s report of seen, silent speech on the synthetic face falls within the range of normal British controls (see figure 1). He shows normal endpoint (values 1 and 4–5) perception and the normal, somewhat nonlinear, function between the two when synthetic, intermediate tokens are presented. Essentially, he handles this visual speech categorization task in much the same way as he does its auditory equivalent.

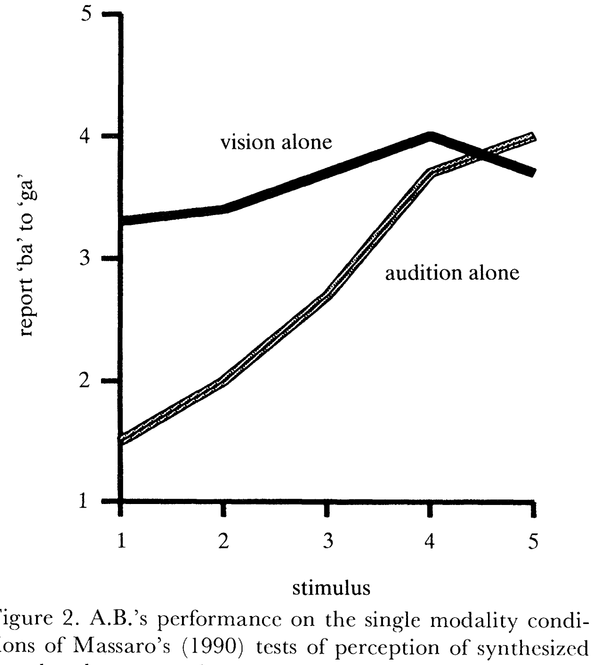

Figure 2. A.B.'s performance on the single modality conditions of Massaro's (1990) tests of perception of synthesized heard and seen speech.

Then, as the family of curves shows (figure 1), H.J.A. is sensitive to the seen face in his reports of heard speech tokens, for the level of the end-point responses changes fairly systematically with the seen face. Again, these functions are well within range of normal controls. H.J.A. is normal in his ability to systematically discriminate seen speech sounds, and in his susceptibility to seen speech in the report of heard speech tokens.†

By contrast, A.B.'s performance on the Massaro task is very odd indeed. For silent speech, her responses to the synthetic face are at chance, whether she sees the face making a closed lip or open mouth sound. This looks as if she is guessing (see figure 2). Yet she is clearly trying to take account of what she sees in reporting the audio-visual tokens, for her reports of what she hears, under these conditions, are different from those she gives when no face is seen and only a heard voice is reported.

Although her ability to sort still lip pictures is abnormal, A.B. was better on such tasks than H.J.A. Yet H.J.A. can see speech through movement, whereas A.B. cannot. H.J.A.'s ability to make use of seen motion in the Massaro test is consistent with what is known of cortical processes concerned with vision, in particular with occipital and temporal areas sensitive to seen movement (Zihl *et al.* 1983; Perrett *et al.* 1990; Vaina *et al.* 1990). In H.J.A. such cortical sites are presumably intact, and he can therefore sometimes use seen movement in visual recognition. In A.B., by contrast, either such sites are not functioning properly or they fail to connect with sites where the representation can undergo further (identificatory) processing. An intriguing question now is whether patients who lose the ability to see form through motion, because of the loss of such cortical regions (Zihl *et al.* 1983), are susceptible to audio-visual fusion illusions.

However, the moving form of seen speech and the still lip photograph differ from each other more deeply than (say) a rotating cube and a still picture of a cube. For seen speech, sensitivity to visual movement may afford recognition not of objects but of events that are dynamically ordered and discrete. This may operate in infancy to support the four-month-olds' ability to discriminate heard and seen speech patterns by eye (Kuhl & Meltzoff 1982, 1984; see Butterworth 1989). Lipreading may be a unique aspect of face processing in this regard: unlike facial expression, where the end-state expression is usually the object of recognition, the word or phrase that is seen on the moving lips is not characterized by the end-state, or indeed by any particular single frame of the action (see discussion point made by D.I. Perrett, p. 44). The changing face-muscle patterns themselves constitute the proximal event for lipreading.

The cases highlighted in this report show us that investigating lipreading in neuropsychological patients can help to delineate functional impairment more clearly, whether the deficit appears to be linguistic (associated with a reading or heard language deficit) or visuo-spatial (objects or faces). Lipreading can be found to dissociate from every type of other receptive ability I have explored. But the pattern of impairment and sparing in different patients is systematic. The following points emerge.

1. Laterality: effective lipreading requires access to a LH phonetic processing site. RH processes may be involved in some aspects of visual processing but do not appear to play a critical role, in contrast to the role of the RH in other face-processing tasks.‡

2. Among the visual processes that need to be intact to support effective lipreading are those that allow the perception of events through seen movement. The dissociated abilities of H.J.A. (moving lips, good; still lips, impossible) and A.B. (still lips, abnormal but not abolished; moving lips, bad) point in new directions for further research.

3. Dissociations and associations can be demonstrated which suggest different components of information processing for lipreading in relation to other visual processes. Farah (1991) has suggested that a componential–non-decomposable distinction underlies all observed neuropsychological patterns of association and dissociation for object recognition. To the extent that non-componential (largely RH) processes are impaired, so patients will show associated object- and face-processing deficits. If componential analytic (primarily LH) processes are impaired, then object recognition deficits will associate with reading deficits. Two of the subjects described here were unable to read: H.J.A. and Mrs T. Both were unable to perform our set of (still) lipreading tasks. Mrs T., at least, could process faces. This would suggest that lipreading, like reading, involves part-by-part analysis of the visual input. Mrs D. was able to lipread, despite her other face-processing problems, which further supports this inference (gestalt-based, non-componential representations or analyses have failed her). The problematic case, as mentioned above, is that of A.B. She was excellent at reading, at auditory speech perception, and was mildly impaired at object recognition. Not only was she unable to process faces for expression or

† The picture with H.J.A. is still not clear. Like A.B., he was dominated by the auditory channel to a greater extent than normal controls in our tests of the McGurk illusion. Moreover he was not normal at live silent lipreading (identifying a lipspoken number). The Massaro paradigm, which forces the subject to make a decision, from a limited range of tokens to every one of many repeated combinations of seen and heard tokens, may provide a more sensitive measure of discriminability of seen-and-heard speech, perhaps because the criterion for response becomes lower. This test approaches a psychophysical exploration of auditory-visual speech sensitivity.

‡ N.G., a 'split-brain' subject, one of the Caltech total commissurotomy series, was examined on tasks where live lipread numbers, presented in central vision, were matched by one-hand, manual yes–no response to unilaterally presented written numerals. In the auditory-numeral analogue of this matching task, N.G. was equally competent with either hemisphere. For lipreading, the results were identical. N.G. can match lipread numerals equally well in the right and the left hemisphere. Her lipreading was entirely normal in all tasks which were done in free vision and required verbal report. Furthermore, in reporting from a display where pairs of faces were seen left and right of a television screen speaking numbers, N.G. was as proficient at reporting the left as the right face, and in this respect was similar to control subjects. At the very least this suggests that effective integration of the hemispheres is not a requisite for lipreading (R. Campbell, unpublished studies).

identity, she was as poor at lipreading as Mrs T. She was particularly impaired at extracting speech information from a seen moving face. A.B. has a very dense problem in analysing faces, whatever component processes may be involved.

A.B.'s pattern of deficit suggests that lipreading cannot be acquired like reading by using lipshapes as 'letters' in recognizing the speech event. Lipreading, indeed, occupies a unique functional position with respect to patterns of spared and impaired processing of visual material. Although it can dissociate from reading and from recognizing faces and their expressions, it nevertheless requires effective face processing to be reasonably pursued.

The cases described here, as well as the controls, were tested in collaboration with many colleagues. These include Marianne Regard, Thedi Landis, Jeanette Garwood, Charlie Heywood, Edward de Haan, Sue Franklin, Glyn Humphreys, Dahlia Zaidel, Eran Zaidel and Rebekah Smith. My thanks to them and apologies to others I have not mentioned here. Dom Massaro kindly made testing material and advice available. The work reported here is supported by MRC Grant G88811259N, and parts of it were supported by an Oxford University Pump-priming grant and by an ESF Twinning Grant.

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Discussion

D. I. Perrett (*Department of Psychology, University of St Andrews, U.K.*). I have tested Mrs T. and Mrs D. with three facial expressions (smile, surprise and anger) depicted solely as dynamic arrays of 25 moving lights attached to the skin. Both subjects were impaired relative to age-matched control subjects (control performance mean correct $\pm$ 1 s.d. from 60 trials $= 52 \pm 2.6$; $n = 6$). Mrs T. was severely impaired (25 out of 60 correct, a score not significantly different from chance, 20 out of 60). Her performance was surprisingly poor given your findings that she can correctly process Ekman facial expressions and match standard photographs to stylized drawings.

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It is reported here that Mrs D. is impaired in judging (static) expressions, and in general she is very poor in describing the mood state of a person depicted in photographs (T. Landis, personal communication). Mrs D. although impaired did surprisingly well in my test of dynamic expressions, scoring 35 out of 60 (significantly above chance, Binomial test, $p < 0.001$).

There are two points to be made from these data. First, it would be wrong to conclude that the only problem that Mrs T. has with faces concerns lipreading. Second, and of more interest, is the potential dissociation between the ability to process faces generally or facial expression specifically using static and dynamic information. Could Professor Campbell comment on the extent to which the static–dynamic is relevant to interpreting the lipreading problems of these and other patients?

R. Campbell. I am aware of Dr Perrett's findings with Mrs T. and Mrs D. I agree that his finding tempers interpretation of Mrs T's visual deficit. However, the evidence is not yet sufficient to justify any sort of conclusion concerning the relative role of static and dynamic information in different face tasks. This is because the exploratory tasks that Dr Perrett and I have so far used are not equatable in terms either of naturalness or of difficulty. I was interested to learn that both patients were impaired on the dynamic expression task compared with controls. It would therefore be premature to conclude that double dissociations may occur independently for different face tasks, as a function of whether they are static or dynamic.

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