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CHANGES IN LATERAL BIAS ASSOCIATED WITH CHANGES IN TASK DIFFICULTY FOR THE PERCEPTION OF CHIMERIC FACES: WHICH COGNITIVE PROCESSES ARE RESPONSIBLE?

by

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ABSTRACT

CHANGES IN LATERAL BIAS ASSOCIATED WITH CHANGES IN TASK DIFFICULTY FOR THE PERCEPTION OF CHIMERIC FACES: WHICH COGNITIVE PROCESSES ARE RESPONSIBLE?

By

Timothy J. Carbary

In the free-viewing chimeric faces test (CFT), adults make judgments about mirror-image chimeras of human faces. On this test, adults usually rely more on cues in their left visual hemispace so that their judgments show a left visual hemispace, or LVH, bias. The bias has been explained as a product of a change in the balance of arousal or activation between the cerebral hemispheres leading to an attentional shift to the side of space contralateral to the more aroused hemisphere. The LVH bias thus is seen as a product of the greater arousal of the right hemisphere.

Like lateral biases in other perceptual tasks, the CFT bias is known to vary in strength and even direction, for individual stimuli as well as for some individual subjects. Inspection of variations of lateral biases in studies that use other stimuli and other stimulus presentation methods suggests that the variations in CFT biases might be related to task difficulty. This *Task Difficulty Hypothesis* was tested in 7 experiments using methods for assessing the existence of the effect as well as its strength and direction. Three possible outcomes were considered: that task difficulty is associated with increased right hemisphere arousal, resulting in a *stronger* LVH bias, on the premise that difficulty invokes the discrimination of relevant from irrelevant information; that it is associated with increased left hemisphere arousal, resulting in a *weaker* LVH bias, on the premise

that task difficulty invokes the use of either a feature-search or verbal analysis; or that it is associated with decreased right hemisphere arousal on the premise that the task becomes more difficult as the quality, or "facedness," of the stimulus is diminished.

Two kinds of chimeric face tests were used. In a 3-face test, subjects judged the similarity of each pair of chimeric faces to an unaltered target face. In a 2-face test, they chose the better exemplar of emotion, femininity, or age in pairs of chimeric faces.

Experiments 1- 4 defined parameters for the remaining experiments and showed that task difficulty does affect the strength of the LVH bias, although the direction of the effect began to be clear only in Experiment 4, which showed that difficulty was associated with a *weaker* LVH bias. Experiment 5 confirmed the effect and its direction, as did Experiments 6 and 7, which showed that the effect also generalizes across different stimuli and methods. Overall results thus supported the Task Difficulty Hypothesis and showed that task difficulty is associated with a weaker LVH bias. With the effect and direction established, the experiments then considered the question of mechanisms. To this end, subjects in Experiments 6 and 7 were asked which of several predefined cognitive strategies they thought they had used during the test; their accounts were consistent with the model, that is, with the hypothesized changes in hemispheric arousal associated with an LVH bias weakened by task difficulty. The subjects' own accounts suggest that the change reflects the adoption of a "first-impression" strategy for easy judgments and a feature-search and/or verbal strategy for difficult judgments. Further analysis also suggests a contribution of "facedness" to the effect. Clinical implications of the results are discussed along with suggestions for further research to validate the underlying assumptions about cortical activity related to the behavioral findings.

DEDICATION

This work is dedicated to my parents, Jim and Nancy Carbary, and to my fiancée, Faye Berry. Each, in their own way, has generously supported my efforts.

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Many people have helped me in my research and in other ways throughout my graduate career. My Dissertation Committee Chair, Professor Lauren Julius Harris, has shown unwavering dedication to his students, holding them to the same high standards exemplified in his own work. He has supported my work and that of his other students with matchless enthusiasm and skill. In particular, through the many drafts of this dissertation, he taught me that to write clearly one must think clearly, and that it is a life-long endeavor.

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Without face models – the many fellow students, faculty, staff, and friends who lent their mugs for use in this research – the work itself could not have been done. Here's looking at you!

The seven experiments described in this dissertation have been reported in a different form at the poster session of the ninth (1998), eleventh (2000), and twelfth (2001) annual meetings of TENNET, a conference of experimental and theoretical neuropsychology, Montreal, Quebec. Accounts also have been published in special issues of *Brain and Cognition* (Experiments 1 and 2: Carbary, Almerigi, & Harris, 1999; Experiments 4 and 5: Carbary, Almerigi, & Harris, 2001; Experiments 6 and 7: Carbary, Almerigi, & Harris, in press). I am grateful to the anonymous referees for TENNET and *Brain and Cognition* for their helpful comments and suggestions. For Experiments 6 and 7, I also thank Academic Press and Professor Harry A. Whitaker, Editor of *Brain and Cognition*, for permission to alter and use the cartoon faces designed by Ley and Bryden (1979) for their research published in the same journal.

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I. INTRODUCTION

Of all the principles about the human brain, perhaps the most familiar is that the cerebral hemispheres play different roles in cognitive functioning, with the left hemisphere taking the lead for speech and language, the right hemisphere for a variety of non-verbal tasks. This generalization has found support for well over a century in studies of functional deficits in brain-injured patients, since the 1950s in behavioral studies of normal persons and callosotomy patients, and most recently in functional radiological imaging studies of patients as well as normal persons. Thus, when speech and language deficits result from brain disease, the associated lesions are typically in the left hemisphere, and when patients show deficits in perception and recognition of faces, objects, and other visual-spatial forms, the lesions are typically in the right hemisphere (see Benson & Zaidel, 1985; Hellige, 1993; Harris, 1999a, for reviews).

Likewise, in studies of normal persons, when complex visual images are shown tachistoscopically in the right or left visual fields (RVF, LVF), letters and words are usually processed more quickly and accurately in the RVF (e.g., Hellige & Webster, 1979; Rizzolatti, Umilta, & Berlucchi, 1971; Umilta, Sava, & Salmaso, 1980; Wagner & Harris, 1994; Zurif & Bryden, 1969), whereas non-verbal targets, including faces, arrangements of dots, and orientations of lines, are usually processed more quickly and accurately in the LVF (e.g., Boles, 1994; Rizzolati & Buchtel, 1977) Similarly, for free-viewing tasks using chimeric faces as targets, most persons show left visual *hemispace* (LVH) biases consistent with the left visual field (LVF) biases found in tachistoscopic, divided visual field studies (e.g., Carlson & Harris, 1985; Hoptman & Levy, 1988; Jaynes, 1976; Luh, Redl, & Levy, 1994; Luh, Rueckert, & Levy, 1991).

Finally, in fMRI experiments, verbal tasks have been associated with greater left- than right-hemisphere activation (Puce, McCarthy, Allison, & Gore., 1996; Breier et al., 1999), whereas non-verbal tasks, including nonverbal tasks including several of those listed earlier, have been associated with greater right than left hemisphere activation (Haxby, Horwitz, Ungerleider et al., 1994; McCarthy, Puce, Gore, & Allison, 1997; Nakamura, Kawashima, Ito, et al., 1999; Puce et al., 1996). Similar effects have been reported in PET studies (Haxby, Grady, Horwitz, et al., 1997; Sergent, Ohta, & McDonald, 1992) and in studies using surface electrode recordings (e.g., Bentin, Allison, Puce, & McCarthy, 1996).

II. WHY ARE THERE LATERALITY EFFECTS?

Practically as soon as the facts of lateral specialization were established, hypotheses were proposed to account for the phenomenon, that is, to explain *why* the hemispheres are differently specialized for language and spatial functions. For at least the last two decades, it has been acknowledged that explanations that focus on the verbal/spatial classification are inadequate primarily because not all lateralized functions have obvious verbal or spatial content. Two examples are praxis and perception of melody, which are lateralized predominately to the left and right hemispheres, respectively.

Nature of Stimulus Processing

The focus of most of the new hypotheses has been less on the content of the lateralized function than on *how* the cerebral hemispheres process the information, on the premise that differences in content will be compatible with different stimulus-processing modes. Over the years, a number of versions of this basic idea have been proposed (for an early review, see Bradshaw and Nettleton, 1981; for a more recent review, see Hellige, 1993). The four examples that follow are only some of the versions proposed. None of them, furthermore, are intended to dichotomize the brain but, rather, to suggest a continuum of function between the hemispheres. Their focus, like the focus of this dissertation, also is on perceptual, especially visual, functions rather than on output, or motor functions.

Part-Whole Processing

On the premise that all visual stimuli require some degree of decomposition into their constituent parts for effective processing, Farah and colleagues (Farah, 1994; Farah, Levinson, & Klein, 1995; Farah, Tanaka, & Drain, 1995; Farah, Wilson, Drain, & Tanaka, 1998) have proposed that the poles of the dimension of specialization are "part-analysis" and "whole-analysis" represented by left and right hemisphere processes, respectively. Using printed texts and faces as examples, the hypothesis is that texts, which require extensive decomposition (into letters, syllables, words, phrases) for analysis, are normally processed more effectively by the left hemisphere, whereas faces, whose parts must be analyzed together, are normally processed more effectively by the right hemisphere. It follows that a face is recognized as a face or as a face expressing a certain emotion not so much from any individual part but from all the parts seen together. For certain emotional expressions, some parts also may be more important than others or may play a special role (e.g., contraction of the obicularis occuli muscles, which is present in a spontaneous, or Duchenne, smile, but absent in a so-called "false" smile).

Feature-Configural Processing

Gauthier and colleagues (Gauthier, Behrman, & Tarr, 1999; Gauthier & Tarr, 1997; Gauthier, Williams, Tarr and Tanaka, 1998) have described the essential processing difference between the hemispheres not in terms of parts and wholes but in terms of stimulus *features* and stimulus *configurations*. Although not committed to seeing these processes as lateralized, they do not object to this characterization (personal communication with M. Tarr, September 2, 1999).

Local – Global Processing

Robertson, Lamb, and Knight (1988) have proposed that the dimension is best characterized as local-global. They based this proposal on their finding that for letter-stimuli composed of smaller letters, patients with left-hemisphere damage had difficulty perceiving the smaller letters that form the larger letter ("local" perception) but not the larger letter itself ("global" perception). Conversely, patients with right-hemisphere damage had difficulty perceiving the larger letter but not the smaller letters. From this, they concluded that perception of the global configuration (larger letter made of smaller letters) is deficient in right-hemisphere patients whereas perception of local features (small letters that form the larger letter) is deficient in left-hemisphere patients.

High – Low Spatial Frequency Processing

Save for variations in the names assigned to the poles of the dimension, the three models described above characterize the difference between the hemispheres in terms of the analysis of parts and the integration of those parts into a whole. Others have proposed that the more fundamental difference lies at the level of sensory information independent of any such "part" – "whole" classification. One such model, by Sergent (1991) as well as Robertson and Delis (1986), focuses on the spatial frequency of the stimulus and proposes that higher frequency information is better processed by the left hemisphere and lower frequency information by the right. In a further development, Irvy and Robertson (1998) have proposed a two-stage model according to which an initial analysis is made in terms of spatial frequency, followed by a second spatial frequency analysis dictated by the demands of the perceptual task (e.g., deploying attention to constituent parts, or to their configuration, as is indicated to be required after the first analysis). They call this the "double filtering by frequency" model.

By their nature, the parts of a whole, or a configuration, are physically smaller than the whole itself and therefore subtend a smaller visual angle. They therefore occur more frequently and require a higher frequency analysis than the configuration of those parts; the configuration, by definition, occurs *less frequently* and requires a relatively lower frequency analysis. That said, the three previously described models and the spatial frequency model are not incompatible; the spatial frequency model may come closer to describing *how* stimulus characteristics are better suited for analysis of parts versus the configuration of those parts.

Task Difficulty

If the strength and even the direction of the laterality effect are influenced by the kinds of processing called for by the task, there is indirect evidence that they also are influenced by the overall difficulty of the task, as indexed by accuracy and reaction time. From a clinical perspective, this is important because task difficulty is progressively scaled in most neuropsychological tasks. Failures on more difficult tasks are less reliable indicators of a disease process than are failures on easier tasks. In clinical practice, it is generally assumed that when tasks are easy, so that most patients perform correctly, they perform the tasks in a similar way. When tasks are more difficult, however, and patients begin to fail, they are more likely to fail for different reasons. For example, failures may reflect sub-standard premorbid achievement (i.e., never having had the requisite level of skill in the first place). They also may reflect the patient's inability to change or shift cognitive strategy to solve difficult tasks in a different way, either because the alternative strategy itself is dysfunctional or because the ability to *change* strategies is dysfunctional. The proposal that task difficulty is related to changes in cognitive processing strategies may also help generate explanations for the unusual co-occurrence of low-end errors with high-end success on some psychometric instruments. In such cases, the strategy for difficult items may be the only strategy available to the patient, and after initial low-end errors, then a change is made to process the task differently, making for higher-end successes.

The evidence for difficulty effects on laterality tasks comes from several of the research paradigms reviewed in Part I. All the evidence, however, is indirect. For example, for naming tachistoscopically-projected letters, when the letters are made more complex or when their font is degraded, presumably making the task more difficult, the usual RVF bias has been found to weaken or even change to an LVF bias (Bryden & Allard, 1976; Hellige & Webster, 1979; Wagner & Harris, 1994). Bryden and Allard (1976) suggested that this change reflects a change in processing style and that complex or visually-degraded stimuli must be "normalized" and perceived as an exemplar of a known stimulus category (e.g., letters must first be recognized as letters) before they can be separated into relevant and irrelevant components for the usual left-hemisphere processing.

For face perception, on divided visual field (tachistoscopic) tasks, the usual LVF bias has been found to change when faces are inverted (Leehey, Carey, Diamond & Cahn, 1978; Hillis, Hiscock, & Rexer, 1995; Luh, 1997), when subjects are cued to attend to facial features rather than to the whole face (Rhodes, 1985), when the task is to discriminate between schematic faces that differ on a single feature (Patterson and Bradshaw, 1975; Bradshaw and Sherlock, 1982; Fairweather, Brizzolara, Tabossi, & Umilta, 1982), and when subjects are shown two different views of a face and asked whether the faces are the same or different (Bertelson,Vanhaelan, & Morais, 1979). Each such condition presumably could make the task more difficult. In these studies difficulty had been operationalized as lowered task accuracy and/or increased response latency.

Given the premises of the stimulus processing hypotheses, the laterality data also suggest that more and less difficult tasks are *performed* differently. The nature of the difference is less clear. Broadly, across stimulus classes, does a more difficult task require a broad configural analysis to identify a stimulus class, or does it require a detailed feature analysis to do so, or is there an interaction between task content (e.g., visual, motor, or verbal) and processing style? Furthermore, will the answers to these questions be the same for all stimulus categories, or will the dynamics be different for different stimulus classes?

Whatever may be the basis for the hypothesized difficulty-related changes in laterality effects, over time and as experience with the stimulus material increases, tasks also normally become *less* difficult as subjects develop facility or familiarity with them. On this view, it has been suggested that laterality effects therefore depend, at least in part, on the subject's level of expertise (Diamond & Carey, 1986; Gauthier et al., 1998; Gauthier & Tarr, 1997; Bruyer & Crispeels, 1992; Rhodes & McLean, 1990). For visual-spatial material, some investigators have proposed that the hallmark of expertise is configural processing of the sort for which the right hemisphere appears to be specialized (Gauthier et al., 1999), whereas non-experts focus on stimulus features, a left hemisphere function, without regard for the relationship of the features to one another.
Gautier and colleagues studied the role of expertise in fMRI experiments using "nonsense" visual stimuli before and after subjects were allowed to develop expertise in discrimination (Gauthier, Anderson, Tarr, et al., 1997; Gauthier, Tarr, Moylan, et al., 2000). As already noted, laterality effects were not the main focus, but in these studies, right hemisphere activation appeared to take the lead (M. Tarr, personal communication,

September 2, 1999). For faces, that is to say *human* faces, however, it seems safe to say that virtually all normal adults are "experts." Right hemisphere, configural processing therefore presumably would be modal, and, for that reason, so would LVF or LVH biases on face perception tasks, which is what the literature indicates.

Collectively, the tachistoscopic and free-viewing studies suggest a relation between what I have taken task difficulty to be task difficulty and the direction and strength of lateral biases. This suggested relation hereafter will be referred to as the Task Difficulty Hypothesis. What the studies do not clearly show is whether or why the effect should be in one direction or another. In the context of the models of cerebral specialization described earlier, one could say, for example, that where increased task difficulty is associated with a decreased LVF or LVH bias, the change is toward local feature analysis, whereas when it is associated with an increased LVF or LVH bias, the change is toward holistic, configural processing. That is to say that task difficulty is associated with a change in processing style and in turn a change in processing style leads to a change in VH bias. These examples obviously do not exhaust the range of possibilities, and the predictions may be different for verbal and non-verbal tasks.

Individual Differences

The proposed role of expertise raises the more general issue of individual differences and how they might figure in the assessment of the Task Difficulty Hypothesis. At least two sources, or kinds, of difference can be envisioned.

Strength of Lateralization

One kind is the strength of lateralization. Laterality effects of the kind described here are generally stronger for right-handers than for left handers. The difference may reflect the greater heterogeneity in unselected samples of left-handers along with the less strictly lateralized function in these individuals (see review in Harris, 1992). Modest sex differences also have been reported, with females showing weaker laterality effects for verbal material but also stronger effects for the perception of emotion represented in faces (Burton & Levy, 1989; Natale, Gur, & Gur, 1983).

Tonic State of Hemispheric Arousal

Another kind of difference is in characteristic hemispheric arousal. Levy and colleagues have presented evidence that individual differences on lateralized tasks reflect differences in tonic state of left versus right hemisphere arousal (Levy, Heller, Banich, & Burton, 1983; Hoptman & Levy, 1988). Some persons, therefore, may have a characteristic, or default, hemispheric style, whereas for other persons, the style may be more malleable and therefore more affected by their subjective experience of task difficulty.

What is the Proximate Processing Mechanism for Visual Hemispace Biases?

The Dynamic Activation-Attention Model

If, according to the Task Difficulty Hypothesis, as has been suggested, task difficulty, moderated by individual differences, affects the strength and even the direction of the lateral bias in visual tasks, what is the *proximate* mechanism underlying the effect? For the tachistoscopic divided visual field paradigm, the conventional interpretation of lateral biases, in consideration of the anatomy of the visual system, is that they are direct products of structural-anatomical connections and the resultant representation of the visual fields in contralateral visual cortex. Thus, for faces and other non-verbal targets, the usual left visual field (LVF) bias is seen as a product of hemisphere-specific information accessing only the preferred (right) hemisphere, accompanied by signal decay prior to any interhemispheric transfer of information. That explanation, however, cannot obviously account for the left visual hemispace (LVH) bias for the *free-viewing* of chimeric faces or for the presence of changes in strength and even direction of the bias in both tachistoscopic and free viewing tasks. For these reasons, a strict structural-anatomic explanation has largely been replaced by more dynamic models.

The particular model adopted for the current series of experiments was first proposed by Trevarthan (1972) and elaborated by Kinsbourne (1970, 1973, 1974) to account for laterality effects on tachistoscopic as well as auditory (dichotic listening) tasks, and then further developed by Levy and colleagues and applied to free-viewing tasks with verbal as well as non-verbal material (Levy et al., 1983; Levy & Kueck, 1986). The model, which may called a *dynamic attention-activation* model, assumes that the levels of arousal in the cerebral hemispheres are generally in reciprocal balance, leading to a fixation of attention straight-ahead in extra-personal space. It then assumes that the balance will be disturbed by stimulation from one or the other side of space or by endogenous unilateral arousal caused by the expectation of a particular kind of stimulus. Finally, it assumes that the imbalance leads to a change in orientation and attention contralateral to the more aroused hemisphere and therefore to a bias in readiness to accept and process input from the visual hemispace on that side. (In keeping with the premises of the model, the general term, visual hemispace, or VH, and the directional terms LVH and RVH, will be used to refer to the lateral biases on tachistoscopic divided visual field tasks as well as on free-viewing tasks.) In other words, the hemisphere specialized for processing particular stimuli becomes differentially aroused, or "primed," when that stimulus class is presented; this arousal is associated with a shift of attention to the opposite side of space. For a face-judgment task, whether the faces are presented tachistoscopically or for free-viewing, to the extent that the right hemisphere is aroused more than the left, attention will be driven to the LVH, enhancing the salience of "face" information to the viewer's left side and giving a processing bias to information on that side. [1]

Two assumptions thus underlie the use of the dynamic activation model to explain the VH biases for judgments of faces and visual-verbal material. The first is that there is greater activation of one hemisphere in response to the stimulus or task – more right-hemisphere activation for faces, more left-hemisphere activation for verbal material. The second is that this activation causes attention to be directed to the contralateral side of space.

Direct support for the first assumption comes from data cited earlier from functional imaging and EEG studies. Indirect support comes from clinical data, also cited earlier, showing deficits in face perception and visual-verbal comprehension associated with right and left brain injury, respectively.

Direct support for the second assumption is harder to obtain, and it depends on how attention is defined. There is, however, indirect support. For visual tasks, attention is usually associated with eye movements towards the visual target, so that subjects showing an LVH bias would be expected to look more or longer to the part of the object appearing in the left hemispace. As Posner and his colleagues have shown, however,

[1] Kinsbourne's model has not gone unchallenged. For a relatively recent test of the dynamic activation-attention model, see the series of 5 experiments and discussion in Reuter-Lorenz, Kinsbourne, & Moscovitch (1990), wherein they demonstrate three principles of the model: 1) that attention is biased to

attention can be directed without eye movements (Posner, Walker, Freidrich, & Rafal, 1983). In these experiments, however, subjects were trained to keep their eyes still while attending to peripheral stimuli. In a more naturalistic setting, deployment of attention is normally associated with changes in eye movements, as in a typical orienting response. For this reason Kinsbourne (1970) proposed that eye movements might be a reliable index of direction of attentional deployment, so that even though attention and eye movements need not be synchronized, under normal circumstances in a free-viewing face perception test, eye movements would be expected to follow the locus of attention. The Task Difficulty Hypothesis therefore predicts changes in lateral deployment of attention related to the perceived difficulty of a visual-spatial task. [2]

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the direction contralateral to the stimulated hemisphere, 2) that biases are not task dependent, and 3) that in the case of a directional conflict, the rightward bias (RVH bias) is stronger.

[2] Research by Harris, Pierce, and Henderson (unpublished data, L. J. Harris personal communication, 1999b) suggests that the relation between eye movements and performance on the free-viewing tasks dissertation is very complex. The majority of their subjects did move their eyes from the vertical midline and did show the usual LVH bias on a face-judgment task, but eye movement and performance were not directly related in any obvious way.

III. TESTING THE TASK DIFFICULTY HYPOTHESIS

As already noted, variations in stimulus and test parameters have been associated with changes in the strength or even direction of the VH bias for verbal as well as non-verbal material, including faces. The main premis of this dissertation, as expressed in the Task Difficulty Hypothesis, is that the changes are directly related to task difficulty. If, as the hypothesis suggests, task difficulty affects the bias by affecting how the task is performed, that might help to account for the individual differences and stimulus-related variations in the strength of the LVH bias on face perception tasks. Within the context of a dynamic activation-attention model, however, the hypothesis makes different predictions for verbal and non-verbal material. As will be explained below, the hypothesis cannot differentiate between two possible explanations for VH bias changes for verbal material, and there is a third possibility that can be tested only in a non-verbal task, which is why, for the current work, the hypothesis was tested with faces.

Proposed Role of Mechanisms as Applied to Visual-Verbal Stimuli

Based on the dynamic activation-attention model, there are at least two ways that task difficulty could weaken the LVH bias for visual-*verbal* material – by *attenuation* of the character of the stimulus and by *normalization* of the stimulus.

Attenuation Hypothesis

Assume that the verbal stimulus is a sequence of letters. Whether it is made more complex (e.g., by adding ornate strokes and curls) or is degraded (e.g., by lowering the intensity or diffusing the font), it is assumed that the letters will be less likely to arouse left-hemisphere "letter processing" areas to the extent that they look less like letters, that is, to the extent that their "letterness" has been attenuated. By default, that would leave the right hemisphere more aroused than the left, causing the perceptual bias to change from the RVH to the LVH.

Normalization Hypothesis

Alternatively, the right hemisphere might become more active not relatively but absolutely, and not by default but directly, if the more complex or degraded stimulus directly activates the right hemisphere instead of the left hemisphere where the stimulus is usually processed. Bryden and Allard (1976) suggested that under these circumstances, what occurs is *stimulus normalization*, a pre-processing of the stimulus if it is not immediately recognized as a letter. They described normalization as a separation of relevant from irrelevant parts, or signal from noise, and they assumed that it is primarily a right-hemisphere process. For degraded or unusually complex verbal stimuli, they further assumed that this process is activated to make sense enough of the stimulus to determine whether it is verbal (letter or word) or something else. The resulting right-hemisphere arousal thus manifests as an LVH bias.

In summary, to the extent that making the visual-verbal task more difficult is associated with a change in perceptual bias from RVH toward LVH, the change may be due either to an *attenuation* of the stimulus character and therefore to lowered arousal of the left hemisphere, or to a *normalization* of the stimulus category, thereby recruiting a different cognitive process functionally represented in the right hemisphere. In either case, the result is a shift of the arousal ratio to the right.

Proposed Role of Mechanisms as Applied to Face Stimuli

For verbal material, both the Attenuation and Normalization Hypotheses predict the same change in bias for difficult tasks – from RVH toward LVH. For non-verbal material, such as faces, they make *different* predictions. For faces, there also is a third way for task difficulty to affect the bias.

Attenuation Hypothesis

Just like letter recognition can be made more difficult to recognize by making the letters look less like letters, so faces can be made more difficult to recognize or to discriminate by making them look less like faces, that is by attenuating their "facedness." One way to accomplish this is to invert them. Inversion may attenuate facedness in at least two ways. First, it may hinder processing at the entry level, therefore requiring at least additional time to determine whether the stimulus is or is not a face. Second, even after an inverted face is determined to be a face, inverting it or inverting some of its features may hinder quick and accurate judgments of face qualities such as its emotion (Thompson, 1980). To this extent, it's less face-like. Some inversion studies have shown that the usual LVH bias weakens or even changes to an RVH bias (Rhodes, Brake, & Allison, 1993), although other studies have not found any change (Kolb, Milner, & Taylor, 1983). Where a change has been found, it has been suggested that the inverted face fails to arouse those right-hemisphere processes normally activated for upright faces (Rossion, Delvene, Debatisse, Goffaux, et al., 2001). In terms of the dynamic activation model, the assumption is that the reduction in right-hemisphere arousal shifts the balance to the left hemisphere, driving the viewer's attention to the RVH.

If, for faces, attenuation of facedness proves not to be associated with a change in VH bias, then two hypotheses remain – the Normalization Hypothesis and the Feature-Analysis Hypothesis (i.e., analysis of features that comprise the facial configuration).

Normalization Hypothesis

Just as it does for letter processing, making face discriminations difficult by degrading them or by making them highly complex through the addition of irrelevant features would require separation of task-relevant from task-irrelevant information. Unlike letter processing, however, if, by this normalization process, right-hemisphere mechanisms are recruited, then the result should be to strengthen, not weaken, the usual LVH bias.

Feature-Analysis Hypothesis

For faces, as noted above, there is a third way for difficulty to affect the bias. Making the task more difficult could precipitate a feature-based analysis. As suggested above, when a face is decomposed and parsed for its features (e.g., nose, mouth), a left hemisphere analysis is most likely to be used. Therefore, in contrast to the Normalization Hypothesis, which predicts that the LVH bias will be strengthened, a Feature-Analysis Hypothesis predicts that it will be weakened.

In summary, each of the hypothesized mechanisms – Attenuation and Normalization for verbal stimuli, and Attention, Normalization, and Feature-Analysis for faces – makes a prediction about changes in the VH bias when perceptual tasks are made more difficult. These predictions are summarized in Table 1.

Overview of the Current Research

The current research consists of a series of seven experimental tests of the Task Difficulty Hypothesis for free-viewing chimeric face tasks. Experiments 1- 4 were designed to test the hypothesis and at the same time to establish stimulus and measurement parameters. With the parameters established, Experiments 5 – 7 were

Table 1. Predicted Effects of Task Difficulty on Hemispheric Arousal and Visual Hemispace Bias for Visual-Verbal Stimuli and for Faces

Visual-Verbal Stimuli	**Predicted Effects**	
hypothesis	**hemispheric arousal**	**visual hemispace (VH) bias**
Attenuation	↓L –R	↑LVH ↓RVH
Normalization	–L ↑R	↑LVH ↓RVH
Face Stimuli	**Predicted Effects**	
hypothesis	**hemispheric arousal**	**visual hemispace (VH) bias**
Attenuation	–L ↓R	↓LVH ↑RVH
Normalization	↓L ↑R	↑LVH ↓RVH
Feature-Analysis	↑L ↓R	↓LVH ↑RVH

L and R are left and right hemispheres; LVH and RVH are left and right visual hemispace biases; the dash (–) represents no hypothesized change, and arrows represent predicted increases or decreases in hemispheric arousal and visual hemispace bias.

designed to test the hypothesis more precisely. Experiments 6 and 7, however, incorporated three important changes. First, instead on relying on the subjects' own judgments of task difficulty, difficulty levels were established by another group, independently of the experimental subjects. Second, in order to achieve experimental control over the level of difficulty for the judgments, specially designed cartoon faces were used in addition to photographic faces. Finally, to identify the cognitive strategies used by the subjects, subjects were questioned about the strategies they used while making their judgments for the tasks they found to be difficult and easy.

All seven experiments also were designed to assess different possible explanations of the Task Difficulty Effect by 1) ruling out the Normalization Hypothesis or by 2) ruling out the Attenuation and Feature-Analysis Hypotheses. For faces, it was supposed that a weakened LVH bias in association with increased task difficulty will falsify the Normalization Hypothesis, leaving the Attenuation and the Feature-Analysis Hypotheses, whereas it was supposed that a strengthened LVH bias will falsify the Attenuation and the Feature-Analysis Hypotheses, leaving the Normalization Hypothesis. Given an outcome where the Attenuation and Feature-Analysis explanations remain, further studies would be needed to test their relative contributions.

IV. PARAMETRIC STUDIES: EXPERIMENTS 1 – 4

Before we can address the question which, if any, of the hypothesized explanations underlies the task difficulty effect, we must establish that the effect exists in the first place and determine whether it is associated with a stronger LVH bias, consistent with the Normalization Hypothesis, or a weaker LVH bias, consistent with the Attenuation and Feature-Analysis Hypotheses. To do this, stimulus, subject response, and effect-size parameters must be defined. As just noted, this was the purpose of Experiments 1 – 4. These experiments used two versions of a free-viewing chimeric face test that has been found to yield a reliable LVH bias. Experiments 1 and 2 used 3-face sets, and, based on these results, Experiments 3 and 4 directly compared 3-face and 2-face sets. Based on these results, Experiments 5 – 7, comprising the principal part of this dissertation, used 2-face sets exclusively. The results of Experiments 1 – 3 also led to changes in the measurement of task difficulty. All three experiments used an indirect measure of task difficulty, whereas Experiment 4 – 7 used a direct measure, as will be explained below.

Experiment 1

In Experiment 1, with 3-face sets, subjects were asked to compare two chimeric faces to an unaltered target face. The target face was located at the top of the stimulus display with the chimeric faces below it. One chimeric face, an "L-L chimera," was made from the left side of the target face and the mirror image of that side; the other, an "R-R chimera," was made from the right side of the target face and the mirror image of that side. After a set of L-L and R-R chimeras was made, the faces were cropped to a uniform size and oval shape, primarily to exclude extra-face cues including the outline of the model's hair. (See Kowner, 1995, for a discussion.) Chimeras were made from black and white photographs of real faces, digitally scanned and manipulated in Adobe® Photoshop. Face models were volunteers from the academic community, including faculty, staff, and students. An example of a 3-face set is shown in Figure 1. For each face-set, subjects performed a two-stage task, first judging how similar the L-L and R-R chimeras were to each other, and then judging which chimera looked more like the target face. The assumption was that the more similar the chimeras were to each other, the more difficult they would be to discriminate from each other or from the target face, thereby making the task more difficult.

The subjects' own ratings of the similarity of the L-L and R-R chimeras thus were used as an indirect measure of task difficulty. The effect of task difficulty on the VH bias, therefore, was assessed by examining the relation between the subjects' L-L and R-R similarity ratings and the strength and direction of their VH bias. An LVH bias meant that the L-L chimera was reliably chosen over chance. Strength of the bias was measured by the overall number of L-L choices.

Method

Subjects. Subjects were 80 undergraduates (72 right-handers, 8 left handers, 46 females, 34 males).

Procedure. Subjects were tested in a classroom in groups of five to ten. Five 3-face sets were used. Each face-set was projected onto the classroom screen via overhead projector. Subjects first were shown a sample face-set with the chimeric faces visible but with the target face covered. They were asked to rate how different the chimeras were from each other on a 7-point scale. After 10 seconds, the target face was exposed and the

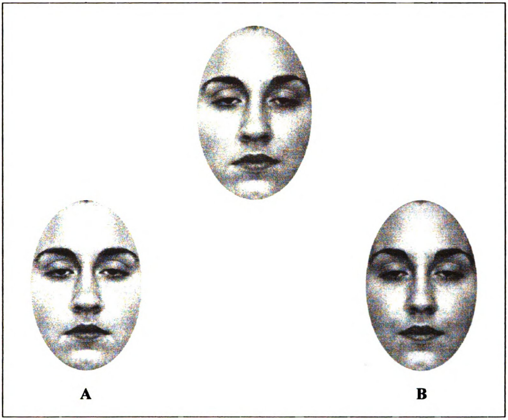

Figure 1. Example of a 3-face set. Face A, an L-L chimera, was made by merging the left half of the target (top) face and its mirror reversal along the midline. From the viewer's perspective, its left side is identical to the left side of the target face. Face B, an R-R chimera, was made from the right side of the target face. From the viewer's perspective, its right side is identical to the right side of the target face.

subjects were asked which chimeric face looked more like the target face. After this, testing continued in the same manner with the five 3-face sets.

Results

For each of the five 3-face sets, a one sample t-test was performed to compare the proportion of subjects showing a VH bias in either direction to the proportion expected by chance (.50). Two of the face-sets showed a reliable LVH bias, two showed a reliable RVH bias, and one showed no bias in either direction. There was no detectable relation between task difficulty based on the L-L and R-R similarity ratings and strength of VH bias, and there were no reliable effects of sex or handedness.

Afterwards, it became clear that a different test could be used to assess the relation between the chimeras' difference-ratings and the strength of VH bias *across* face-sets. To that end, face-sets were rank-ordered in two ways: by mean strength of LVH bias and by mean rated differences between the L-L and R-R chimeras. Rankings were such that a positive correlation would mean that an increasing LVH bias was associated with a *decreasing* difference between the chimeras and/or that an increasing RVH bias was associated with an *increasing* difference between the chimeras. Although the Pearson r correlation between the two variables was an encouraging +.69, it was not reliable and had a reasonable probability ($p = .2$) of being a random effect.

Discussion

Although reliable VH biases were found, they were not consistently in the same direction across face-sets, and no relation was found between the VH biases and the similarity ratings. In contrast, however, to the planned correlational analysis where the N was 80, the post-hoc analysis yielded a promising but statistically unreliable relation, but because the N was only 5, the statistical power of the analysis was greatly reduced.

Experiment 2

For Experiment 2, instead of a post-hoc analysis like the one in Experiment 1, a planned comparison was made. To determine the number of face-sets necessary to achieve acceptable statistical power for the analysis, a power calculation was performed based on the results of Experiment 1. The results indicated that twenty face-sets would give a power of 75% to detect a correlation of .50 in the predicted direction.

Method

Subjects. Subjects were 59 undergraduates (53 right-handers, 9 left handers, 46 females, 34 males).

Procedure. Subjects were tested in a classroom in groups of five to ten. The procedure was identical to Experiment 1 but with twenty face-sets instead of five.

Results

Of the twenty face-sets, six showed a reliable LVH bias, six a reliable RVH bias, and eight showed no bias in either direction. Again, there were no reliable effects of sex or handedness. Of the twelve face-sets showing a reliable LVH or RVH bias, for only two was the bias strength related to task difficulty, one a stronger *LVH* bias, the other a stronger *RVH* bias.

All twenty face-sets were rank-ordered by mean strength of LVH bias and by mean rated differences between the chimeras. The Pearson *r* correlation between the two variables was .01 ($p<.98$), again non-reliable. The same correlational analysis then was performed for only those twelve face-sets that elicited a reliable LVH or RVH bias. The result was a non-reliable Pearson *r* of .16 ($p<.62$).

Discussion

Although Experiment 1 showed a high but unreliable correlation from an unplanned post-hoc test, consistent in direction with the Normalization Hypothesis, the results of Experiment 2, with better statistical power, were non-reliable, with no obvious directional trend. Both experiments, however, also yielded overall weaker LVH biases than obtained previously in our laboratory when face-sets were presented in booklet form rather than via overhead projection, as in Experiments 1 and 2, and this may have contributed to the absence of a reliable relation between task difficulty and VH bias.[3] If so, then establishing a reliable LVH bias must be the first requirement for testing the Task Difficulty Hypothesis. To help meet this requirement in the subsequent experiments, all test stimuli therefore were presented in booklet form. Along with this change, face-sets were scrutinized for whether or not they produced a reliable VH bias in Experiment 2. Twelve did, and one nearly did. This left seven 3-face sets that, for unknown reasons, showed little propensity to elicit a bias. Those seven were culled, leaving thirteen face-sets for continued use. Other studies in our laboratory also have found larger overall VH biases with 2-face than with 3-face sets.[4] If the overall VH bias is more reliable with one format than with another, the more reliable format should boost statistical power due to reduced dispersion of the data. However, if a more reliable LVH

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[3] In Experiments 1 and 2, strength of VH bias for face perception also may have been influenced by what Boles (1994) described as input variables (e.g., stimulus characteristics like luminescence and size), possibly by the large size of the projected face-set or by the contrast of a dim testing room with an illuminated face-set.

[4] There may be several reasons for the difference in the strength, reliability, and direction of the VH bias between the 2-face and 3-face sets. That discussion, however, is beyond the scope of this paper.

bias is confirmed with 2-face sets, a different measure of task difficulty also would have to be developed. These considerations guided the design of Experiment 3.

Experiment 3

In Experiment 3, along with the thirteen 3-face sets from Experiment 2, fourteen 2-face sets were used, consisting of eight "happy-neutral" (HN) face-sets, three same-sex young-old (YO) face-sets, and three male-female (MF) face-sets. The HN chimeras were made from a smiling half-face merged along the vertical midline with a neutral half-face. Both half-faces were of the same face model, whereas the YO and MF face-sets were necessarily made from different face models. All 2-face sets consisted of a chimera and its mirror reversal, one above the other. For the HN face-sets, subjects were asked which face looked happier; for the YO face-sets, which face looked younger; and for the MF face-sets, which face looked more feminine. Examples of each kind appear in Figure 2. For each kind, choosing the chimera with the relevant cue(s) (happier half, younger half, more feminine half) to the subject's left would constitute an LVH choice.

The 2-face sets were used so that the strength, direction and reliability of LVH bias could be compared for the 3-face and 2-face formats. As already noted, if one format is more reliable, its use should boost statistical power due to reduced dispersion of the data.

Method

Subjects. Subjects were 103 undergraduates (96 right-handers, 7 left-handers; 88 females, 15 males).

Procedure. Two test booklets were prepared to counterbalance the left – right position of chimera for the 3-face sets and the top – bottom position of chimeras for the

Figure 2. Examples of 2-face sets: happy-neutral (HN) on the left, masculine-feminine (MF) in the middle, young-old (YO) on the right. All chimeras were constructed in the same way except that for the HN chimeras the two halves came from the same face model. Thus, each HN chimera consisted of a smiling half-face and a neutral half-face of the same face model joined along the midline. On a single test page an HN chimera and its mirror reversal were shown, one above the other. For one of the chimeras, the smiling half appeared in the subject's left visual hemispace (LVH), the other in the right visual hemispace (RVH). Therefore, if subjects chose Face A as the happier chimera, that is, the one with the smiling half to their left, that would constitute an LVH choice. Similarly, for the MF and YO chimeras, choice of faces B and A as, respectively, the more feminine and older faces would constitute LVH choices.

2-face sets on the stimulus page. In each booklet, the thirteen 3-face sets came first, followed by the eight 2-face sets, for a total of 21 sets. Similarity ratings (to be used as the index of task difficulty) were only made for the 3-face sets because the chimeras in the 2-face sets are mirror reversals and cannot reasonably be judged for similarity. The difficulty measure used for 3-face sets therefore is not compatible for use with a 2-face set. All subjects were tested together in a large classroom.

As in Experiments 1 and 2, the subjects were told that they would be asked to perform a two-stage task. Beginning with a sample 3-face set, they were asked to indicate on a 7-point scale how similar the two faces (L-L and R-R chimeras) were to each other, and then to choose which face was more similar to the third, target face. In contrast to Experiments 1 and 2, to help subjects understand the scoring method and to help reduce variability by standardizing responses, subjects were shown a face-set of identical L-L and R-R chimeras and were told that they were examples of two *identical* faces that should be scored 1, or "identical," on their response sheet. Then they were shown very dissimilar L-L and R-R chimeras and were told they should be scored 7, "low similarity."[5] After that, an entire 3-face set was shown.[6] The L-L and R-R chimeric faces were pointed out at the bottom of the face-set, and the subjects were asked to rate their similarity on a scale from 1 to 7 and to record their answer on their response sheets by circling one of the points on a numbered line.

After they completed the thirteen 3-face judgments, subjects made judgments for the eight 2-face HN chimeras, three YO chimeras, and three MF chimeras for a total of

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[5] The chimeras used for the "identical" demonstration were identical. The chimeras used for the "low similarity" demonstration were the L-L and R-R chimeras from Experiment 1 rated least similar to one another. Both faces used for these demonstrations were then retired from the bank of test faces.

fourteen 2-face judgments. As with the 3-face judgments, subjects first were shown via overhead projection a sample 2-face set for HN chimeras. The faces were labeled A and B and were placed one above the other. Subjects were told that some of the test items would look like this example and that, depending on the face-set, they would be asked to judge which face was happier, which face was older, or which face was more feminine. (See again the examples in Figure 2.) Then, for a single practice trial, they were asked to judge which face was happier and to indicate their choice by circling A or B on their response sheet. Subjects then were guided through their stimulus booklet, item by item, with spoken instructions from the test administrator. They were instructed to turn the pages together and to wait for instructions before doing so. For example, for the 3-face sets, the test administrator said, "Turn the page. Item six, how different are the two faces at the bottom of the page? (pause) OK, which face at the bottom of the page looks most like the one at the top?" Subjects were allowed ten seconds to mark their response.

Results

3-Face Sets. Of the thirteen 3-face sets, six showed a reliable LVH bias, three showed a reliable RVH bias, and four showed no bias in either direction. This analysis had a probability of .77 to detect an effect of .15 in the predicted direction. Again, there were no reliable effects of subject sex or handedness.

For each of the thirteen 3-face sets, Pearson *r*s were calculated to assess the relation between the difference-rating for the chimeras and the strength of the VH bias for that face-set. Only one correlation was reliable ($r = -.25$, $p<.05$), for one of the three 3-face sets that yielded an RVH bias. In other words, for none of the thirteen face-sets was

[6] Overhead projection was used only for the sample items only, so that the entire group received the same instructional examples.

the strength of the difference-rating between the L-L and R-R chimeras directly related to the strength of the LVH bias, but for one face-set, a greater difference was related to a stronger *RVH* bias. This analysis, with an n of 103, had an 87% probability to detect a correlation of .3 in either direction.

Correlational analysis yielded the same results for men and women when their data were analyzed separately. There was, however, a slight sex difference for rated similarity of L-L and R-R chimeras (on a 7-point scale, men's mean = 4.52, women's mean = 4.05, $t = 2.09$, 101 df, $p<.04$).

As planned, all thirteen 3-face sets were rank-ordered by mean strength of LVH biases and also by the mean difference-rating between their chimeras. The Pearson *r* correlation between the two variables was -.39 ($p = .18$), again non-reliable. This test, however, had power of only 56% to detect a correlation of .50 in the predicted direction.

The same correlational analysis then was performed for only those nine 3-face sets that elicited a reliable LVH or RVH bias. The result was a non-reliable Pearson *r* of -.54 ($p = .13$).

Finally, for these same nine 3-face sets, the mean chimera difference-ratings were compared for the six LVH-sets and the three RVH-sets. The comparison failed to show any difference ($t = 1.9$, 7df, $p = .10$). This analysis, however, with seven degrees of freedom, had very low statistical power.

2-Face-Sets. Unlike the 3-face sets, all fourteen 2-face sets (HN, YO, MF) showed overall strong, reliable LVH biases. Of the eight HN face-sets, subjects made LVH choices 65% of the time ($t = 5.3$, 102df, $p<.001$), with the difference reliable for six face-sets and borderline for the remaining two ($p = .06$ and $p = .09$). Of the three YO face-sets, subjects made LVH choices 74% of the time, with the bias reliable for all three face-sets (t = 7.8, 102df, p<.001). Of the three MF face-sets, subjects made LVH choices 70% of the time , again reliable for all three face-sets (t = 6.8, 102df, p<.001).

Discussion

As expected, the booklet administration yielded VH biases for the majority (nine of thirteen) of 3-face sets, with the majority being LVH. Again, however, the results did not support the Normalization Hypothesis. Instead, as in Experiments 1 and 2, of the 3-face sets that showed a VH bias, difficulty was related more often to a *weaker* rather than a stronger LVH bias, the reverse of what is predicted by the Normalization Hypothesis but consistent with the Attenuation and Feature-Analysis Hypotheses (see Table 1).

As expected, the overall LVH bias also was stronger for 2-face than for 3-face sets: twelve of the fourteen 2-face sets but only 6 of the 13 face-sets showed reliable LVH biases, and the individual biases for the 2-face sets were stronger. Based on these findings, it was decided to test the Task Difficulty Hypothesis with the 2-face as well as the 3-face task. As already noted, this would require a new measure of task difficulty, because the measurement developed for the 3-face task (assessment of similarity of LL and R-R chimeras) would not be possible for the 2-face task. In Experiment 4, therefore, a more direct measure, magnitude estimation, was used for both the 3- and 2-face sets. Subjects performed two tasks for each face-set (3-face and 2-face sets): first, they made the appropriate face judgment; then, using magnitude estimation, they rated the difficulty of that judgment. Use of this difficulty measure allowed for data analysis similar to that used in Experiments 1 – 3 but now for both kinds of face-sets.

Experiment 4

Method

Subjects. Subjects were 121 high school students in introductory and advanced psychology courses (115 right-handers, 6 left-handers; 78 females, 43 males).[7]

Procedure. Subjects were tested in much the same way as in Experiment 3. However, after seeing a sample 3-face set and judging which chimera looked more like the target face, subjects were asked how they would rate the difficulty of their judgment (A or B) if the average difficulty were given a rating of twenty points, and to record that number on their response sheet.

After the 3-face task, subjects were shown a sample 2-face set for HN chimeras. After choosing the happier face, they were given the parameters noted above and asked to rate the difficulty of that judgment. For the next fourteen 2-face sets, subjects were allowed ten seconds per judgment, asked to rate the difficulty, then prompted to turn to the next face-set in unison. All subjects were tested in their classrooms, and their teacher, after training in our laboratory, administered the test.

Results

3-Face Sets. For each of the thirteen 3-face sets, a one sample t-test was used to compare the proportion of subjects showing a VH bias in either direction to the proportion expected by chance (.50). Five face-sets showed a reliable LVH bias, three showed a reliable RVH bias, and five showed no bias in either direction. This test had 73% power to detect a difference of .15 in either direction. No sex or handedness

[7] At the time Experiment 4 was planned, the opportunity presented itself to test high school students. There was no *a priori* reason to suppose that the results would differ because of the approximately 3-year age difference between them and the undergraduates used in the other experiments and in light of evidence that hemispace bias does not change within this age range (Levine & Levy, 1986).

differences were found; however, the test for a handedness effect was weak due to the limited number of left-handers.

For each of the 3-face sets, Pearson *rs* were calculated to assess the relation between the subjects' estimated difficulty (now measured by magnitude estimation) of each judgment and the strength of the VH bias for each face-set. Of the thirteen correlations, three were reliable ($p<.05$), two of them, however, for face-sets that did not elicit a reliable left or right VH bias. In other words, for only one of the thirteen face-sets was difficulty related to a *weaker* LVH ($r = -.21$, $p< .02$). This test had statistical power of 92% to detect a correlation of .30 in either direction. In Experiment 4, unlike Experiment 3, there was no difference between the men's and women's overall estimations of task difficulty.

As planned, all thirteen face-sets were rank-ordered by mean strength of LVH bias and by the mean rated differences between their chimeras. The Pearson *r* correlation between the two variables was -.34 ($p = .25$), again non-reliable. However, this test had statistical power of only 44% to detect a correlation of .50 in either direction. The same correlational analysis on only those eight face-sets that elicited a reliable LVH or RVH bias now yielded a non-reliable Pearson *r* of -.36 ($p = .38$).

Finally, for these same eight face-sets, the mean chimera difference-ratings were compared for the five LVH-sets and the three RVH-sets. The comparison failed to show any difference ($t = 1.1$, 6df, $p = .31$). This analysis, with 6 degrees of freedom, had very low statistical power.

2-Face Sets. Overall, the fourteen 2-face sets (HN, YO, and MF) again showed strong and reliable LVH biases. For the 8 HN face-sets, subjects chose the chimera with the smile in their LVH 67% of the time ($t = 6.9$, 120df, $p<.001$), with seven of the eight HN face-sets eliciting reliable LVH biases. The 3 YO face-sets elicited an LVH bias 79% of the time ($t = 11.2$, 120df, $p<.001$). The 3 MF face-sets elicited an LVH bias 75% of the time ($t = 10.4$, 120df, $p<.001$). As in Experiment 3, every YO and MF face-set elicited an LVH bias. Only for the MF face-sets, however, were there sex differences in VH bias strength, with women showing a stronger LVH bias for the MF 2-face sets (men's mean = 71% LVH choices, women's mean = 84% LVH choices, $t = 2.55$, 118df, $p<.012$).

Unlike Experiments 1 – 3, the subjects rated the fourteen 2-face sets as well as the 3-face sets for perceived task difficulty. For each 2-face set (HN, YO, and MF), Pearson *r*s were calculated to assess the relation between the subjects' estimated difficulty of each judgment and the strength of the VH bias for that judgment. The relationship was reliable for only one face-set ($r = -.23$, $p<.013$), indicating that for that face-set, the more difficult the judgment, the weaker the LVH bias. This analysis had statistical power of 92% to detect an effect size of $r = .30$ in either direction. The pattern of correlations between VH bias and task difficulty was the same for men as it was for the entire group. No face-set, however, showed such a relationship when women's data were analyzed separately.

When all fourteen 2-face sets were rank-ordered by mean strength of LVH bias and mean estimated difficulty, the Pearson *r* correlation between the two variables was -.32 ($p = .27$), again non-reliable. This test had power of only 47% to detect a correlation of .50 in either direction.

Discussion

As in Experiments 1 – 3, the results failed to support the Normalization Hypothesis for either 2- or 3-face sets and instead showed a consistent but infrequently reliable relationship in the direction predicted by the Feature-Analysis and Attenuation Hypotheses. For the 3-face sets, one correlation was consistent with those hypotheses. The results also showed that the magnitude estimation method was successful. For the 2-face sets, the relation between task difficulty and VH bias strength was found to be in the same direction as for the majority of 3-face sets in Experiment 3. Again, only one of the correlations, now for the 2-face sets, was reliable and again consistent with the Feature-Analysis and Attenuation Hypotheses.

V. PRINCIPAL STUDIES: EXPERIMENTS 5 – 7

So far, none of the experiments support the Normalization Hypothesis. That is, they fail to show that increased task difficulty is associated with a strengthened LVH bias. Before either the Feature-Analysis or Attenuation Hypotheses can be accepted as alternatives, however, we must be confident that the Normalization Hypothesis can be definitively rejected. To find out will require further experiments. These experiments can be designed with stimuli, parameters, and estimated effect-sizes based on findings from Experiments 1 – 4, but, as noted in the Overview of Current Research in Part III, they incorporated four important changes based on the following considerations.

First, is the relation between LVH bias and task difficulty peculiar to these methods of assessing VH bias and task difficulty, or does it generalize to other methods? For example, could the use of self-ratings for task difficulty play a role because subjects perform the task expecting some items to be easier and some to be more difficult? To find out, difficulty ratings would have to be standardized prior to the experiment, and subjects would have to be kept naive to variation in task difficulty.

Second, there are at least two possible explanations of the relation between task difficulty and a weaker LVH bias that involve increased left-hemisphere activity. One is that the weaker LVH bias reflects increasing left hemisphere arousal because of the introduction of a feature-based analysis; another is that it reflects the introduction of a verbal analysis. In the context of the dynamic attention-activation model, the activation of left-hemisphere language strategies may account for the same data as the Attenuation and Feature-Analysis Hypotheses, which means that a left-hemisphere, language mediated strategy will have to be considered as well. To better understand the nature of the processing used and to find out whether one of the remaining strategies was, in fact, being used, subjects in Experiments 6 – 7 were asked directly to describe the strategy, or style of processing, used for their judgments,

Third, in Experiment 5, as in Experiments 1 – 4, the chimeric faces were made from photographs of real faces. For those faces, the quality of the displayed emotion varied in unknown and uncontrolled ways. In Experiments 6 – 7, to achieve a greater measure of control over the displayed emotion, two different kinds of specially designed drawings of faces were used in addition to the photographic chimeras.

Finally, in Experiments 5 – 7, only the HN 2-face sets were used. The reason was that in Experiment 4, HN face-sets yielded LVH biases around 70%, compared to 75% for MF and 79% for YO biases. Use of the HN face-sets therefore would allow for a clearer expression of the effect of difficulty on the LVH bias by lessening the possibility of a ceiling effect. In Experiment 4, HN face-sets, unlike MF face-sets, also did not elicit sex differences. Using only the HN chimeras in Experiment 5 –7 therefore made it more likely that the men's and women's scores could be pooled for greater statistical power. Although this would come at the expense of potentially finding a sex difference, it was decided that this was outweighed by the advantage of pooling the scores.

In sum, Experiment 5 was designed to replicate the consensus finding of Experiments 1 – 4 and therefore to confidently rule out the Normalization Hypothesis; Experiments 6 and 7 were designed to test whether the task difficulty effect generalized beyond the established experimental protocol; and Experiment 7 was designed to better understand the nature of the processing strategies used by the subjects.

Experiment 5

Method

Subjects. Subjects were 358 university students (281 right-handers, 57 left-handers, 13 ambidexters; 256 females, 95 males).

Procedure. Thirty-four HN 2-face sets were prepared in the manner previously described. Each face-set was used only once. Two test booklets were prepared in order to counterbalance the position of face-sets on the stimulus page. (See the example of HN face-sets in Figure 2. See also Appendix A for examples of photographic HN face-sets common to Experiments 5 –7.) Subjects were tested in groups of five to ten in a classroom. They were shown a sample 2-face set and then were told that for all test items, they would be asked to judge which face was happier. After making the judgment for the sample, they were asked how they would rate the difficulty of their judgment if the average difficulty were given a rating of 20 points, and to record that number on their response sheet.

Results

LVH Bias Effects. Over all thirty-four face-sets, the mean LVH bias was 68% ($t = 12.1$, 351df, $p<.001$). There was no sex difference in the size of the bias (women 68.3%, men 67.8%; $t = .14$, 349df, $p<.89$), but there was a handedness effect ($t = 2.50$, 336df, $p<.01$). Left-handers made LVH choices 60% of the time (different from chance $t = 2.37$, 56df , $p<.02$); right-handers made LVH choices 70% of the time (different from chance, $t = 2.50$, 336df, $p<.01$).

Difficulty Ratings. On the difficulty ratings, there was no handedness difference (right-handers' mean = 21, left-handers' mean = 22, $t = .34$, 336df, $p<.79$), but there was a sex difference, with men rating the task as more difficult than women (men's mean = 24, women's mean = 21, $t = 2.8$, 349df, $p<.006$).

LVH Bias Effects by Level of Difficulty. The overall correlation between subjects' mean difficulty ratings for the thirty-four face-sets and mean LVH bias scores for those face-sets was $r = -.12$ ($p<.02$). This analysis had statistical power of 81% to detect an effect size of $r = .15$ in either direction.

For each of the thirty-four face-sets, Pearson *r*s were calculated to assess the relation between the subjects' estimated difficulty for each of the thirty-four judgments and the strength of the VH bias for each face-set. Thirteen of the thirty-four correlations were reliable ($p<.05$), and six more approached significance ($p<.10$). These nineteen correlation coefficients were all negative and ranged from -.09 to -.19, indicating that the *more difficult* the judgment, the weaker the LVH bias, or, said differently, the greater the change toward an RVH bias. Data for the right-handed subjects yielded the same results as for the entire group (i.e., thirteen of thirty-four correlations were reliable). When the same analysis was conducted on only the left-handers' scores, only two of the thirty-four correlations were reliable. Finally, when the men's and women's scores were analyzed separately (collapsed over handedness), three of the thirty-four correlations were reliable for men, nine of the thirty-four correlations for women.

As planned, all thirty-four 2-face sets were rank-ordered according to their mean strength of LVH bias and their mean estimated difficulty. The Pearson *r* correlation between the two variables was -.22 ($p = .21$) but was non-reliable. This test had a one-tailed power of only 54% to detect a correlation of .30. When analyzed separately, left-handers showed a non-reliable correlation ($r = -.14$, $p<.30$), and right-handers showed a reliable correlation (r = -.13, p<.03). When analyzed separately neither men nor women showed reliable correlations (men: r = -.20 , p< .27; women: r = -.24 , p< .17).

Discussion

Again, no support was found for the Normalization Hypothesis for 2-face sets; instead the relation between task difficulty and VH bias was in the reverse direction. For about half the stimulus face-sets (across all subjects), there were reliable relationships between subject-perceived task difficulty and a *weakening* of the LVH bias usually associated with this type of chimeric face-set. Furthermore, across all face-sets, only right-handers showed this relationship. In sum, the results showed a small but reliable relation between self-rated task difficulty and a *weakening* of the LVH bias.

There may be several reasons for the presence of a reliable effect in Experiment 5 and its absence in Experiments 1 and 2 and the mixed results in Experiments 3 and 4. Most likely it was due to the relatively low power in the earlier experiments to detect a small effect, and, secondly, to the use of 3-face sets in Experiments 1 – 3 with an indirect measure of task difficulty. In retrospect, the (non-reliable) *post hoc* positive correlation (r = + .69) between task difficulty and strength of LVH bias in Experiment 1 was misleading. Even with their shortcomings, Experiments 2 – 4 frequently showed a *negative* relation between LVH bias and task difficulty. Indeed, the reliable results of Experiment 5 are in the same direction as the majority of statistically reliable results in the earlier experiments.

So far, task difficulty has not been independently manipulated; it was based on the judgments of the same subjects who had made the face judgments. In the last two experiments, therefore, task difficulty was manipulated and assessed independently, prior to administration of the protocol. As already noted, it was hypothesized that the change in the LVH bias reflected the incorporation of a feature-based analysis, but another possibility must be considered – that more difficult items engender a strategy incorporating verbal analysis of the stimuli. To better understand the nature of the processing strategies used, subjects were asked about the style of processing they employed while making their judgments. Finally, in Experiments 6 and 7 two different kinds of specially designed face cartoons were used in addition to the chimeras made from photographs of real faces in an effort to achieve a greater measure of control over the displayed emotion, and, therefore, task difficulty.

Experiment 6

Method

Subjects. Subjects were 212 university undergraduates (212 right-handers; 158 females, 54 males).

Test Faces. Test stimuli were twenty-three pairs of chimeric faces. Two different kinds of faces were used to make the chimeras. Eight of the twenty-three face-sets were made from photographs of real faces. (See again the example in Figure 2.) They were drawn from a pool of thirty-four face-sets, each of which had been independently rated for difficulty to judge by the 358 subjects from Experiment 5. The eight chosen for Experiment 6 were the four rated "easiest" and the four rated "most difficult" to judge (shown in Appendix A). The remaining fifteen face-sets were made from five different cartoon faces. Three were from a set of realistic faces originally designed by Ley and Bryden (1979) to depict different levels of emotion ranging from extremely negative to extremely positive. For the current study, only the three faces depicting the neutral, mildly positive, and extremely positive expressions were used. The remaining two cartoon faces were more schematic than the Ley and Bryden faces. They were designed, however, to depict the same three levels of emotion depicted in the Ley and Bryden faces, that is, neutral, mildly positive, and extremely positive. For each of the total of five cartoon faces, three face-sets were made such that the hemi-smile increased in magnitude incrementally, creating what was intended to be three levels of judgment difficulty – easy, medium, and difficult. The three pairings for one of the Ley and Bryden faces and for one of the line-drawn cartoon faces are shown in Figure 3; all cartoon face-sets are shown in Appendix A.

Pilot Studies to Establish Task Difficulty. For the cartoon faces, two pilot studies were conducted to confirm the three levels of difficulty created by the design of the face-sets. In Pilot Study 1, eighteen subjects were shown three pairs of chimeric faces made from one of the Ley and Bryden faces and were asked to choose the happier face of each pair and then to *rank order* the three sets according to the difficulty of the judgments. The results were in almost perfect agreement (Pearson $r = .98$, $p<.001$) with the intended difficulty ranking. In Pilot Study 2, eighteen other subjects were asked to choose the happier face of each pair of all fifteen cartoon face-sets and immediately after each judgment to *rate* each judgment as "easy," "medium," or "difficult." The face-sets were presented one after the other, in pseudo-random order. These ratings yielded only two levels of difficulty instead of three as in Pilot Study 1. In Pilot Study 2, the "easy" and "medium" face-sets received comparable ratings ($F = 7.08$, 14df, $p<.009$). Each, however, was rated as easier to judge than the "difficult" face-sets (LSD post-hoc

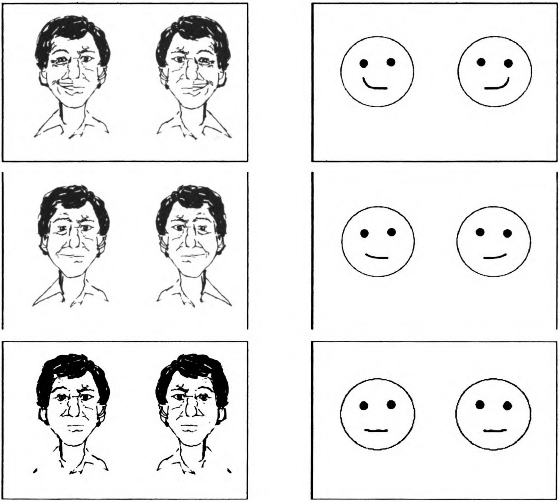


Figure 3. Examples of Realistic and Line-Drawn Cartoon Chimera Face-Sets. Cartoon face-sets are shown for three levels of judgment difficulty: easy (top), medium (middle), and difficult (bottom), for realistic cartoon chimeras (left) and line-drawn chimeras (right).

difference between "easy" and "difficult", $p<.003$; "medium" and "difficult", $p<.028$; "easy" and "medium", $p<.254$). The results, nonetheless, were in close agreement (Pearson $r = .72$, $p<.001$) with the intended order of difficulty.

Procedure. All subjects were tested together in a large classroom. They first were shown a sample face-set (labeled face A and face B) via overhead projection, asked to judge which face was happier, and then told that they would be asked to make the same kind of judgment for other pairs of faces depicted in their test booklets. The booklets contained the twenty-three face-sets, each on a separate page. The subjects then were guided through the twenty-three face-sets, one at a time, by the test administrator. They were allowed ten seconds per face-set and were asked to mark their choice (face A or face B) on their response sheet.

Following the twenty-three judgments, the subjects were directed to another part of their response sheet and were asked three self-report questions about their more *difficult* judgments. They were instructed as follows: " For the judgments you just made, you probably found that some were quite easy to make and some were more difficult. For the judgments that were more difficult to make, did you: 1) talk to yourself about how to decide; 2) study small features of the face while trying to decide; or, 3) decide in some other way?" Subjects were told that "talking to themselves" did not necessarily mean talking aloud and that any sub-vocal, or internal, verbalization should be counted. They also were asked to mark all answers that applied and to briefly elaborate if they marked "decided in some other way." Subsequently, the three self-report categories will be referred to as "feature-search," "self-talk," and "some other way," respectively.

Results

LVH Bias Effects. For all twenty-three faces-sets, the mean LVH bias was 0.66 ($t = 11.73$, 211df; $p<.001$). Biases for the eight photographic and fifteen cartoon face-sets were nearly identical, 0.67 for the photographic face-sets, and 0.65 for the cartoon face-sets. Both means were different from chance ($t = 9.55$, 211df, $p<.001$ and $t = 11.13$, 211df, $p<.001$, respectively) but not from each other ($t = 1.54$, 211df; $p = .13$).

LVH Bias Effects by Level of Difficulty. For the photographic face-sets, the LVH bias was 0.71 for the four "easy" sets ($t = 10.10$, 211df; $p<.001$) and 0.64 for the four "difficult" sets ($t = 7.04$, 211df; $p<.001$), with both means different from chance. A one-way ANOVA indicated that the biases were reliably different from each other (difference = .064; $F = 4.90$, 423df; $p = .027$).

For the cartoon face-sets, the LVH bias was 0.67 for the five "easy" sets ($t = 8.95$, 211df; $p<.001$), 0.68 for the five "medium" sets ($t = 10.16$, 211df; $p<.001$), and 0.60 for the five "difficult" sets ($t = 6.35$, 211df; $p<.001$), with all three means different from chance. An ANOVA showed that these biases were different from each other ($F = 6.27$, 634df; $p = .002$). LSD post-hoc tests also revealed reliable differences between the biases for easy and difficult face-sets (difference = .07; $p = .009$) and between the medium and difficult face-sets (difference = .08; $p = .001$) but not between the easy and medium face-sets (difference = .01, $p = .459$). The bias strengths are shown in Figure 4.

A 2-tailed Pearson correlation for the photographic face-sets showed an inverse relation of $r = -.11$ between the two levels of task difficulty and LVH bias ($n = 424$; $p = .027$). Likewise, for the cartoon face-set for which the pilot studies indicated only two levels of difficulty, the correlation was $r = -.14$ ($n = 636$; $p<.001$).

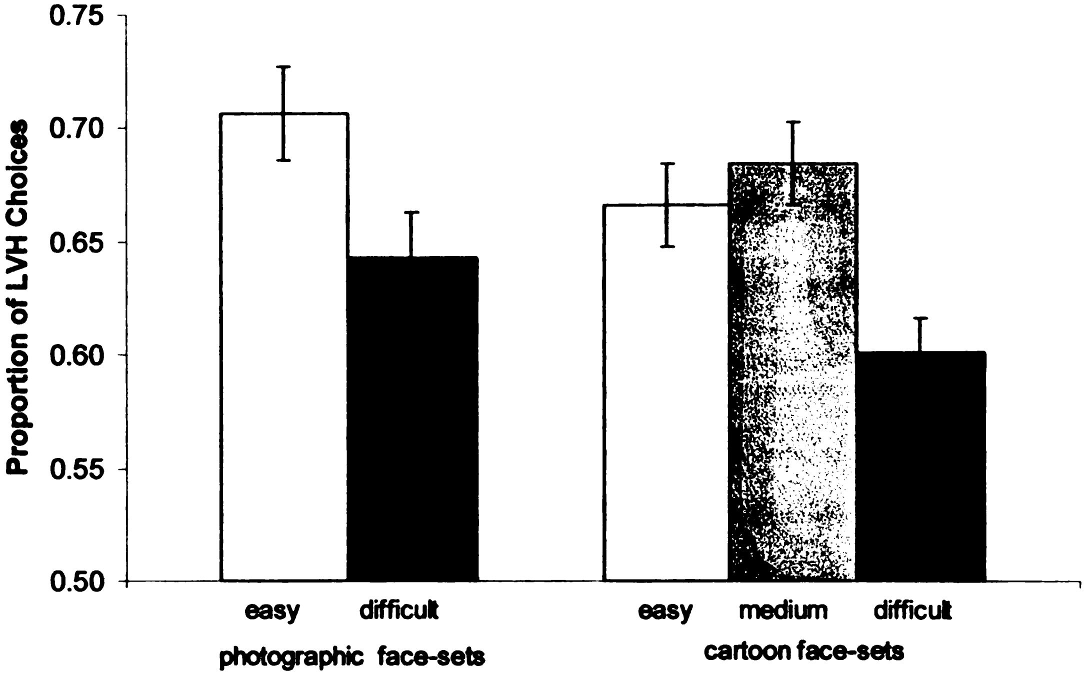


Figure 4. Strength of LVH bias for easy through difficult judgments for photographic and cartoon face-sets for Experiment 6. The figure shows the relation between strength of LVH bias and level of difficulty. Non-overlapping standard error bars indicate statistical reliability.

Self-Report Questions. For the more *difficult* judgments, 47% of the subjects checked "self-talk," 90% checked "feature-search," and 23% checked "some other way." Several subjects who checked "some other way" and explained that they had made their choice based simply on their first impression. See Table 2 (page 52).

Discussion

In sum, when task difficulty was defined and validated independently, it had the same effect on the VH bias as it did in Experiment 4 and earlier experiments. The results thus further support the Task Difficulty Hypothesis and allow the confident rejection of the Normalization Hypothesis.

Based on the self-report data, the results also suggest that the change in the VH bias from left to right is more closely related to the use of a feature-search style of analysis than to the use of verbal mediation. The self-report data, however, were incomplete because subjects were asked only about the judgments they found to be difficult, not the ones they found to be easy. Before the more difficult judgments can be confidently associated with any particular strategy or strategies, self-report data are needed for both kinds of judgments, easy as well as difficult. The results also showed that subjects who checked "some other way" often noted that their choice was based on their first impression. If "first-impression" had been included among the categories, it therefore might have increased the validity of individual choices.

With these considerations in mind, Experiment 7 was designed with two procedural changes. Self-report questions were asked for the easy as well as the difficult judgments, and "first impression" was added as a 4^{th} category.

Experiment 7

Method

Subjects. Subjects were 82 university undergraduates (82 right-handed; 66 females, 16 males).

Test Faces. Test booklets and face-sets were the same as those used in Experiment 6.

Procedure. The testing procedure also was the same except that, as already noted, in the self-report period, subjects were asked about their easy as well as their difficult judgments and were given "first impression" as a 4th category.

Results

LVH Bias Effects. For all twenty-three face-sets, the overall LVH bias was 0.67, virtually identical to the score in Experiment 6 and, again, reliably different from chance ($t = 7.83$, 79df; $p<.001$). Likewise, the biases for the eight photographic and fifteen cartoon chimeras were very similar to those in Experiment 6 and, again, very similar to each other, 0.70 for the photographic chimeras and 0.65 for the cartoon chimeras, with both biases again different from chance ($t = 6.59$, 79df; $p<.001$ and $t = 7.12$, 82df; $p<.001$, respectively) but not from each other ($t = 1.30$, 79df; $p = .20$).

LVH Bias Effects by Level of Difficulty. For the photographic face-sets, the LVH bias was 0.71 for the four "easy" face-sets ($p<.001$; $t = 6.01$, 79df) and 0.70 for the four "difficult" face-sets ($t = 7.04$, 79df; $p<.001$) (For these and some remaining analyses, the degrees of freedom are discrepant due to casewise deletions for missing data points.) This time, a one-way ANOVA indicated that the biases for the easy and difficult face-sets were not reliably different from each other (difference = .017; $F = 1.50$, 158df; $p = .223$), although the direction of the effect was the same as in Experiment 6.

For the cartoon face-sets, the LVH bias was 0.71 for the five "easy" face-sets ($t = 6.859$, 79df; $p<.001$), 0.67 for the five "medium" face-sets ($t = 5.372$, 79df; $p<.001$), and 0.58 for the five "difficult" face-sets ($t = 3.497$, 79df; $p = .001$). A one-way ANOVA showed reliable differences between the LVH biases per difficulty level ($F = 5.05$, 239df; $p = .005$). LSD post-hoc tests revealed reliable differences between the easy and difficult face-sets (difference = .129; $p = .001$) as well as between the medium and difficult face-sets (difference = .087; $p = .029$). As in Experiment 1, an LSD post-hoc test showed no difference between the biases of the easy and medium difficulty groups (difference = .040; $p = .291$). These results are shown in Figure 5.

For the photographic face-sets, a one-tailed Pearson correlation showed a non-reliable relation, $r = -.028$, between task difficulty and LVH bias ($n = 160$; $p = .364$). For the cartoon face-sets, a one-tailed Pearson correlation for all three levels of difficulty showed a reliable relation between task difficulty levels and LVH bias ($n = 240$) of $r = -.21$ ($p = .001$).

Self-Report Questions. For the judgments that the subjects said were more *difficult*, 51% checked "self-talk," 92% checked "feature-search," 17% checked "some other way," and 66% checked "first impression." For *easier* judgments, 22% checked "self-talk," 28% checked "feature-search," 2% checked "some other way," and 93% checked "first impression." Table 2 lists the percentage of subjects reporting use of each strategy.

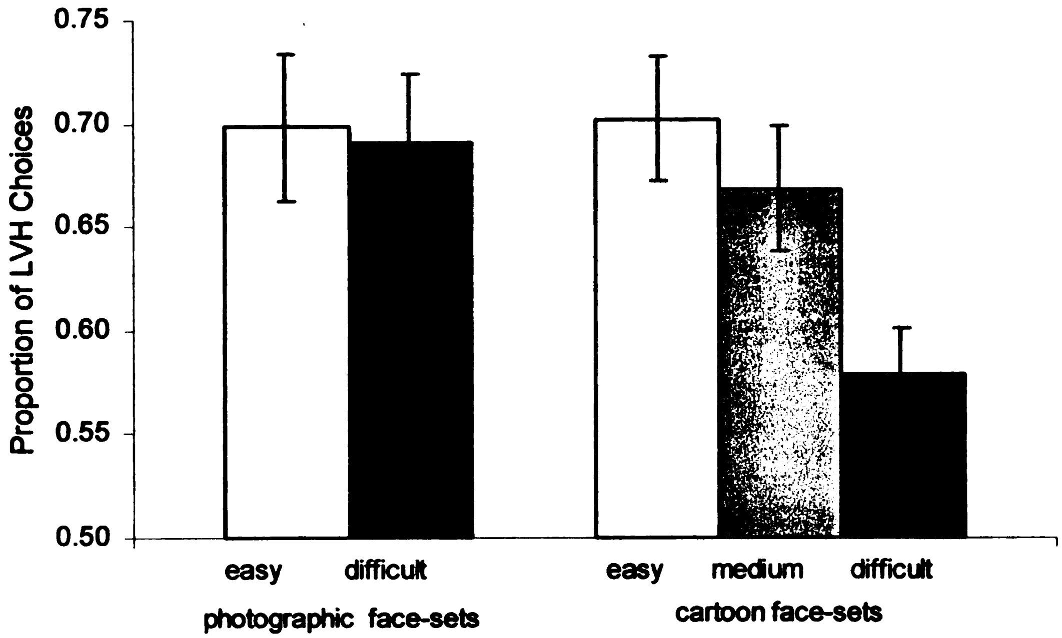


Figure 5. Strength of LVH bias for easy through difficult judgments for photographic and cartoon face-sets for Experiment 7. The figure shows the relation between strength of LVH bias and level of difficulty. Non-overlapping standard error bars indicate statistical reliability.

Table 2. Percentage of Subjects Reporting Use of Each Strategy on Difficult Judgments for Experiment 6 and on Difficult and Easy Judgments for Experiment 7

		Experiment 6 n = 212	Experiment 7 n = 82
self-talk strategy	difficult	**47%**	**51%**
	easy		**22%**
feature search strategy	difficult	**90%**	**92%**
	easy		**28%**
some other way	difficult	**23%**	**17%**
	easy		**02%**
first impression	difficult		**66%**
	easy		**93%**

Discussion

The main results further confirm the task difficulty effect in Experiment 6. They also confirm the finding indicating the predominance of the "feature-search" over the "self-talk" strategy for difficult tasks and show that both strategies, but especially "feature-search," are associated more closely with difficult than with easy judgments. Finally, they show that for easy judgments, "first impression" was the overwhelming strategy reported. In combination, the results suggest that when the judgment is sufficiently easy, subjects can rely only on first impression, precluding the need for any other strategy.

It has been long established that feature-oriented processing is associated with the left hemisphere and that configuration-oriented processing is associated with the right hemisphere. This series of experiments shows that task difficulty is associated with chsanges from one hemisphere and processing style to another. Still, however, a very interesting question remains, namely, which leads which? Does task difficulty precipitate a change in hemisphere and style of processing, or does a change in hemisphere and style of processing precipitate the experience of difficulty? The current experiments were not designed to address this question, but addressing it is a very interesting, logical next step.

VI. SUMMARY AND GENERAL DISCUSSION

Overall, the results support the Task Difficulty Hypothesis, that is, that task difficulty is related to the strength of the VH bias for the judgment of emotion in chimeric faces. After testing the hypothesis while at the same time establishing stimulus and measurement parameters in Experiments 1 – 3, a task difficulty effect emerged in a consistent direction by Experiment 4, and in Experiments 5 – 7 its strength and direction were established and replicated, with the effect each time being a weakening of the LVH bias as task difficulty increased. In Experiment 5, the same subjects made the face judgments who assessed task difficulty, and in Experiments 6 and 7, difficulty was independently assessed and subjects also were asked to identify the cognitive strategies they thought they had used to perform the task for difficult judgments in Experiments 6 and 7 and for difficult and easy judgments in Experiment 7.

Status of Hypotheses

With the task difficulty effect established for different kinds of face-sets and different ways of assessing difficulty, the question is how do the results fit the different hypothesized explanations? They clearly rule out the Normalization Hypothesis, lean strongly toward the Feature-Analysis Hypothesis, and possibly suggest a role for the Attenuation Hypothesis.

Normalization Hypothesis

By the Normalization Hypothesis, more difficult face-sets, like the more difficult letters and fonts tested by Bryden and Allard (1976) and by Wagner and Harris (1994), would have to be perceptually "normalized" so that relevant and irrelevant information could be distinguished and so that a stimulus class or category could be established to assist further processing. The current experiments, however, repeatedly showed that the LVH bias, instead of being strengthened, as predicted by the Normalization Hypothesis, was weakened.

Feature-Analysis Hypothesis

The direction of the effect thus supports the Feature-Analysis Hypothesis, consistent also with the subjects' self-reports, in Experiments 6 and 7, of their predominant use of a feature-search strategy and, secondarily, of linguistic cueing for the difficult judgments. Therefore, if a weakening of the LVH bias reflects an increase in left-hemisphere arousal, these results suggest that the change in bias mostly reflects the introduction of a feature-search strategy.

Attenuation Hypothesis

Although the results show that task difficulty is related to the use of feature search, the Attenuation Hypothesis has not been ruled out. That is, a weakening of the LVH bias with increasing task difficulty might still be accounted for by a reduction of right hemisphere arousal resulting from diminished "facedness" of the target stimulus. Although a direct test of this possibility was not planned in the designing of the current experiments, a rough kind of test is possible. Recall that in Experiments 1 – 5, the chimeric faces were made from photographs of real faces, whereas in Experiments 6 and 7, in addition to the photographic faces, two kinds of specially designed cartoon faces were used: the more realistic Ley and Bryden cartoons and the more schematic line-drawn cartoons. After designing the cartoon chimeras, it became clear that the photographic chimeras looked more like real faces than either kind of cartoon face, with the line-drawn chimeras showing the least resemblance. This permitted comparison of the overall LVH bias (collapsed over task difficulty) across the three levels of "facedness."

The results, summarized in Figure 6, suggest that the LVH bias was stronger for photographic face-sets and realistic cartoon face-sets than for line-drawn cartoon face-sets. For the combined data from Experiments 6 (n = 224) and Experiment 7 (n = 89), the overall LVH bias was 0.67 for photographic face-sets, 0.66 for more realistic cartoon face-sets, and 0.62 for line-drawn face-sets. Results from a one-way ANOVA indicated that the biases were reliably different from each other ($F = 3.13$, 937df; $p = .044$), and LSD post-hoc analysis showed reliable differences in the strength of the LVH bias between line-drawn and photographic face-sets ($p<.023$) as well as between line-drawn and realistic cartoon face-sets ($p<.043$), but not between photographic and realistic face-sets.

One possible interpretation of the difference in strength of LVH bias between the line-drawn faces and other faces is that the usual right-hemisphere mechanisms were less aroused for the less face-like faces. Unfortunately, although each kind of face-set was collapsed over difficulty level for this analysis, there is no way to tell whether the line-drawn face-sets *generally* were more difficult to judge because task difficulty cannot be co-varied out of the analysis. The results nonetheless are suggestive and can be used in designing new studies of the independent contribution of facedness to the difficulty effect.

Interpretation of Data from Other Studies

How well do these hypotheses explain results from other face-perception studies that show a change toward (or reversal to) an RVH bias? The Feature-Analysis Hypothesis

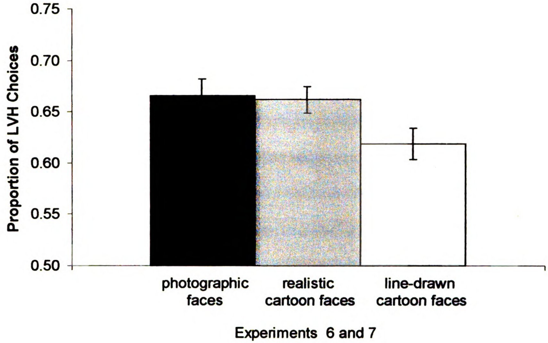


Figure 6. Strength of LVH biases for photographic, realistic cartoon, and line-drawn cartoon face-sets for Experiments 6 and 7. The data collapsed over difficulty level, showing potential relation between strength of LVH bias and degree of "facedness." Non-overlapping standard error bars indicate statistical reliability.

accounts for results that show this change when subjects are cued to attend to facial features rather than to the whole face (Rhodes, 1985) and when subjects must discriminate between schematic faces that differ on a single feature (Patterson and Bradshaw, 1975; Bradshaw and Sherlock, 1982; Fairweather, Brizzolara, Tabossi, & Umilta, 1982). It is less clear how it accounts for the effect when subjects are asked to make same-different judgments of two different views of the same face (Bertelson, Vanhaelan, & Morais, 1979). The Attenuation Hypothesis, on the other hand, would seem to help to explain the weakening of the LVH bias when faces are inverted and therefore look less like a face (Leehey, Carey, Diamond & Cahn, 1978; Hillis, Hiscock, & Rexer, 1995; Luh, 1997). As noted in the Introduction, however, none of these studies determined whether the weakened or reversed LVH bias was associated with an increase in subjective difficulty.

VII. CONCLUSIONS AND FUTURE QUESTIONS

Difficulty and Cognitive Strategy

Overall, the results suggest that when a visual judgment task becomes more difficult, subjects rely less on right-hemisphere strategies and more on left-hemisphere strategies. A major aspect of the change appears to be in the increased reliance on stimulus features and, to a lesser extent, on the use of a language-based strategy. Further studies are needed to assess the contribution of stimulus character (e.g., facedness). At this time, it also remains to be seen whether and to what degree these strategies are interrelated.

Individual Differences

Questions also remain about what the individual brings to the task as opposed to what the task itself elicits. For example, as discussed previously, individual differences in lateral specialization as indexed by handedness and, possibly, by the sex of the subjects may be related to lateralized hemispheric arousal and, perhaps, in processing style as well. The current experiments were not specifically designed to address these questions, and, with respect at least to the handedness variable, the number of left-handers was usually too small to permit meaningful analysis. Experiment 5 (with 281 right-handers and 57 left-handers) showed a difference in the overall strength of the bias, with right-handers showing the stronger LVH bias, which is consistent with the literature. In that Experiment, right-handers and left-handers showed virtually the same relation between bias strength and task difficulty, although the latter was not statistically reliable. Inspection of scores across the seven experiments, however, did not reveal any other obvious trends in the data. The possible role of handedness in the further elucidation of the task difficulty effect thus remains for further research.

By contrast, for comparisons of the sexes, the Ns were adequate. Only in Experiment 4, however, did men and women differ on LVH bias strength, with women showing a stronger overall LVH bias for MF face-sets. As noted previously, this difference was not pursued in the subsequent experiments so that data for men and women could be pooled for a more powerful analysis of the relation between task difficulty and LVH bias strength. There was also an unexpected finding of a sex difference: for an indirect measure of task difficulty in Experiment 3 using 3-face sets and then for a direct measure of task difficulty in Experiment 5 using 2-face sets. In both cases, men rated the CFT as an overall more difficult task than did women. In neither case, however, were there sex differences in the relation between task difficulty and the strength of the bias.

As discussed previously but not addressed directly in these experiments, there also is reason to believe that a further role may be played by individual differences in characteristic style of hemispheric arousal independent of lateralized motor or perceptual dominance. Finally, individual differences in experience with any stimulus class or particular kind of test as well as learning history for the use of one or another processing style might be expected to contribute to a task being "easier" and therefore less likely to evoke a difficulty-related feature-search strategy. Like the other individual difference variables, the possible contributions of characteristic style of hemispheric arousal and experience/expertise remain for further research.

Attention-Arousal Model

Assuming that attention is lateralized to the hemispace contralateral to the more aroused cortical hemisphere, a fundamental tenet of the attention-arousal model, we can now characterize the direction of changes in hemispheric arousal when task difficulty changes. At this point, however, we can only speculate about changes in arousal *within* each hemisphere. For example, if there is a significant increase in left-hemisphere activity is introduced with increased task difficulty, are those newly aroused areas the homologues of the right-hemisphere areas, or are they different altogether? To the extent that left-hemisphere processing is associated with a different style of cognitive processing, the greater likelihood is that the areas would be different. For example, one would expect to find activation of left frontal eye fields and of left parietal and subcortical structures associated with attentional control as well as some degree of activation of left-hemisphere frontal and temporal language areas. Likewise, most normal adults being "face experts" so that all face judgments are normally easy, one would nearly all face judgments to be processed predominantly in the right hemisphere, with the right posterior fusiform gyrus taking the lead, and with an LVH bias as a result. The fusiform gyrus has been implicated for both expert processing and for face processing (Gauthier, et al., 1997; Kanwisher, McDermott, & Chun, 1997; Puce et al., 1996), and it presumably will be active for any face perception task – easy or difficult. The introduction of task difficulty is unlikely to recruit left-hemisphere mechanisms peculiar to an alternative strategy to the exclusion of fusiform activation. Therefore, to the degree that the introduction of a feature-search strategy has increased left-hemisphere arousal, it would not be expected to replace arousal in areas usually associated with face perception in normal subjects; instead it should activate areas that could introduce complementary processing strategies. One way to address all such questions and possibilities would be through real-time neuroimaging studies of the concurrence of VH bias, difficulty level, and local arousal.

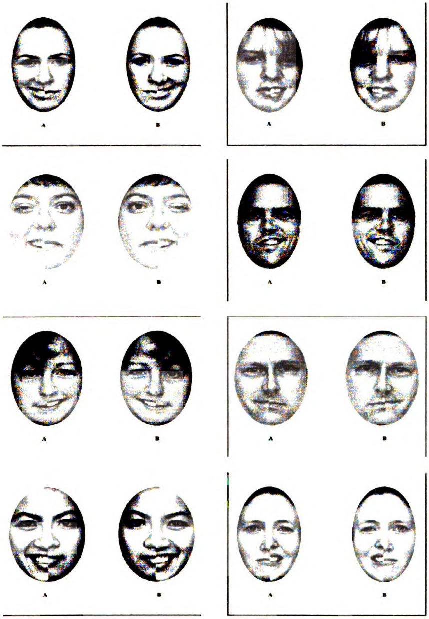
Accuracy of Self-Report

Functional imaging also could help to determine whether and to what degree subjects' post-hoc reports of their strategies coincide with physiological changes found to be associated with the task difficulty effect. For instance, would subjects who reported talking to themselves for more difficult judgments show activation of known language areas, and would subjects reporting use of feature analysis show activation of areas known to be involved in feature searching (e.g., eye fields directing visual scanning, frontal areas associated with sequencing for point-to-point comparisons), or would their reports be unrelated to the strategies implied by actual patterns of arousal?

Clinical Implications

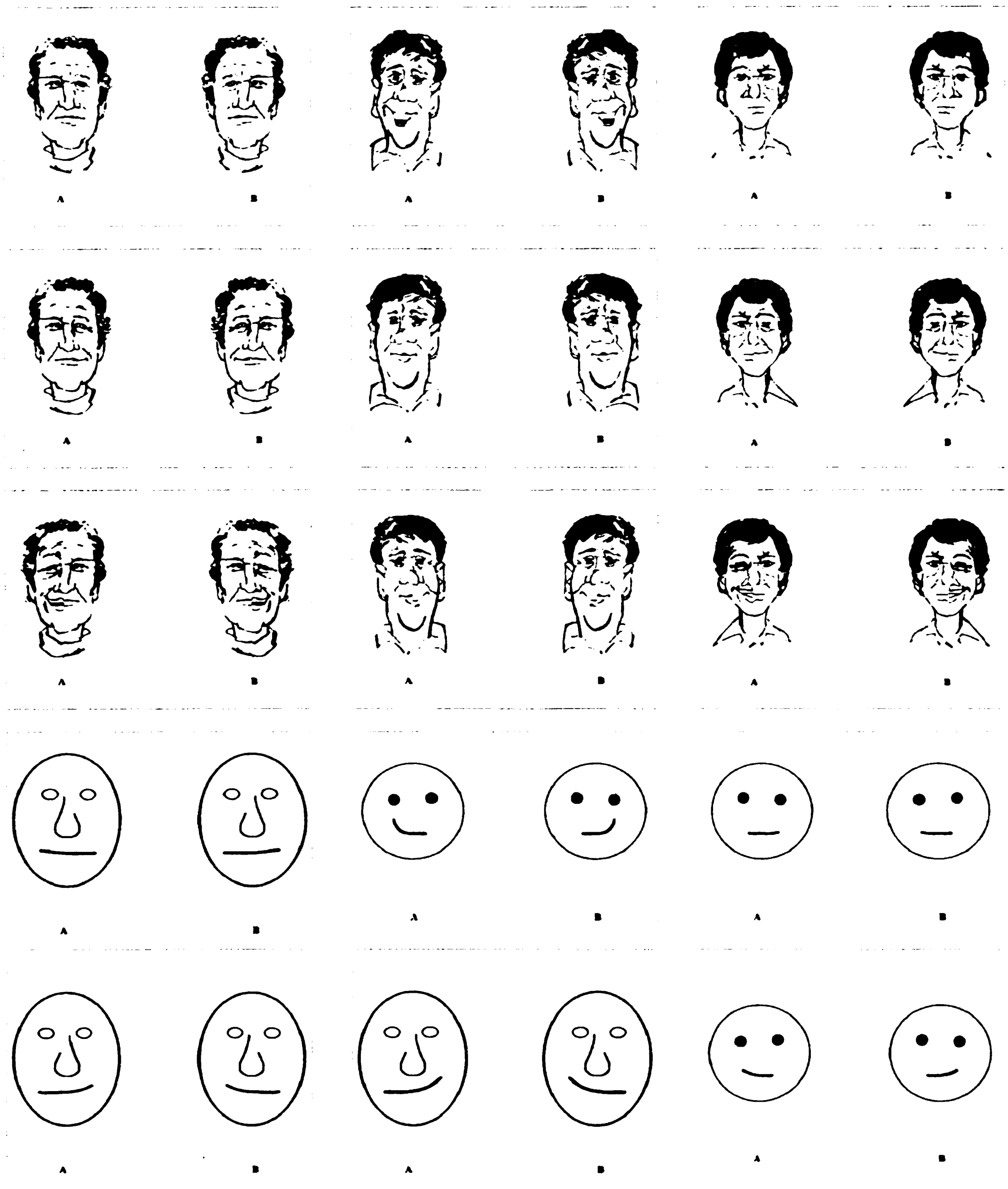
Finally, the results have at least three kinds of implications for clinical practice. First, consider the interpretation of neruropsychological test results. As noted previously, insofar as task difficulty is progressively scaled in most neuropsychological tests, then failures on more difficult items may reflect either a low initial level of skill or, based in part on the current research, the patient's inability to shift strategies. Second, the possibility that task difficulty is related to cognitive processing strategy may help generate alternative hypotheses for the unusual co-occurrence of low-end errors with high-end success on some psychometric instruments (a pattern sometimes associated with test dissimulation). After an injury, a patient may show deficits for processing test items in the usual way, while the ability to shift strategies remains intact. Being unable to process the easy items in the usual way, low-end errors are made from the outset, but then a shift in strategy may occur, and from that point on test items are approached with the cognitive strategy usually reserved for more difficult items. Third, research in rehabilitation may help to determine, following an injury that has compromised a patient's ability to shift strategies, whether shifting cognitive strategies for difficult tasks can be trained or cued.

APPENDIX A



Photographic face-sets from booklets used for Experiments 6 and 7. In order from top left and from left to right, face-sets shown are from pages 1 through 8, booklet A. Booklet B showed the same face-sets in the same order but with positions A and B reversed. These eight face-sets are from the pool of 34 photographic face-sets used in Experiment 5 and represent the four rated most difficult (Experiment 6 and 7; pages 1, 3, 6, and 8) and the four rated easiest (Experiment 6 and 7; pages 2, 4, 5, and 7).

APPENDIX A (continued)



Realistic and line-drawn face-sets from booklets used for Experiments 6 and 7. Continuing in order from top left, and from left to right, shown are face-sets from pages 9 through 23 from booklet A. Booklet B showed the same face-sets in the same order, but with positions A and B reversed.

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