hemisphere, the difference between musicians and nonmusicians should reside mostly in an improvement in the left-ear performance rather than a decrease in right-ear performance. This is numerically the case in each of the five recent studies that bring out an overall left-ear superiority (table 10.8).

In brief, being musically sophisticated is associated with an advantage in the left hemisphere for relational processes applied to music and in the right hemisphere for holistic musical tasks. Musicians are not more left-hemisphered for music; rather they are more differentiated hemispherically. The hypothesis that complex holistic templates can be learned from experience raises the possibility of a developmental pattern in which people oscillate between first treating a skill holistically, then relationally as experience with it increases, and then holistically again (with higher-order holistic templates the second time). The next section explores face recognition as potentially such as skill.

FACE RECOGNITION: A DEVELOPMENTAL CASE STUDY

A general point of this chapter is that language is characteristically a left-hemisphered skill because most language behaviors involve relational processing. Language is of more interest than many other skills, such as long division or skiing, because it is an indigenous part of all cultures, shared by all "normal" individuals. The ability to recognize faces also seems to be a likely candidate for a culturally universal skill (though it would be less surprising to find a culture in which individuals are not recognized by their faces than to find a culture in which nobody speaks a language). The recognition of familiar faces is important to consider because it is generally viewed as a function of the right hemisphere. This would be a prima facie counterexample to the proposal in this paper that a distinct processing style, not skill, is associated with the hemispheres. Of course, it is possible that faces are always recognized holistically, and that is why face recognition is right-hemisphered. However, I will argue that the generally accepted facts about face recognition are best understood as involving both right and left hemispheres, depending on the way a face is recognized. This variability is a function of such factors as the developmental stage of normal children or neurological state of brain-damaged adults. A full review of the face-recognition literature is beyond the scope of this paper. The

reader should consult Carey (1978) for a recent review of most of the facts that I shall discuss.[9]

Typical specific phenomena are the following:

1. The bilateral recognition of photographs of acquaintances is good with little change, starting at age five years (Carey and Diamond, 1977).
2a. Inverted photographs of acquaintences are poorly recognized in children and adults, except
2b. At ages twelve to fourteen (Carey and Diamond, 1977).
3a. By age eight years, people recognize photographs of familiar people better in the left visual field except
3b. Famous faces (movie stars, and so forth) are better recognized in the right visual field (Marzi et al., 1974).
4a. The recognition of recently presented faces is based on paraphernalia (hats, glasses) until age ten, when each face becomes a perceptual constant. The overall ability to recognize recently presented faces increases with age up to age fourteen except
4b. At ages twelve to fourteen there is a decrease.
5a. Recently presented faces are recognized equally well in the visual fields between ages seven and ten; at ten they are better recognized in the left visual field. This asymmetry continues throughout life except
5b. At ages twelve to fourteen, the left and right visual fields perform equally well (Leehey, 1976).
6. The recognition of upside-down presentations of recently presented faces is poor throughout life.
7a. With (posterior) right-hemisphere lesions, adults cannot recognize recently presented faces, but
7b. Right-hemisphere-damaged adults can recognize familiar faces, and
7c. In certain cases, characteristically with bilateral (posterior) lesions, adults cannot recognize familiar faces but can recognize recently presented ones.

Carey argues that facts such as these (except 3b, which appeared after Carey, 1978, was written) suggest that there is, in effect, an organ of face recognition, which inhabits (and is facilitated by) a particular region of the right hemisphere. A hypothesis is that this organ has two related physiological substructures in the right hemisphere, an early maturing one for familiar faces and a later maturing one for unfamiliar faces.

This hypothesis is certainly possible. If true, it would serve as a clear example of a maturationally based sociopsychological skill. However it is a very strong position and it cannot explain any of the exceptions noted in 2b, 3b, 4b, 5b, 7b. There is, moreover, a weaker hypothesis that would account for all the stipulated facts. The principles are the following.

A. Recognition of a small number of frequently presented family members and caretakers is important for the child.
B. The face offers a relatively constant and distinctive configuration for each person.
C. There are several ages when the number of individuals to be distinguished increases rapidly (in the social selection of subjects discussed in the literature): (1) at ages five to seven (when a child enters grammar school); (2) at ages twelve to thirteen when a child enters high school).
D. The left hemisphere emerges developmentally as dominant for relational processing, and the right hemisphere for holistic processing.
E. Holistic templates of increasing complexity are constructed developmentally as a result of being repeated in relational analysis.

Principles A–C are obviously true, at least at a nontechnical level; D and E have been postulated earlier in this paper to account for other data. It remains to show how A–E describe facts 1–7 (I take the nonexceptional facts first).

1. Principles A and B combine to predict the early emergence of family (and friend) face recognition.
2. Upside-down familiar faces are of no special import (and rarely experienced).
3. Principles A, B, and D together predict that familiar face recognition will emerge as a special right-hemisphere skill in childhood. Repeated presentation of the same small number of faces could build up a multiple representation of each that could be represented holistically.
4. To recognize discriminatively a recently and briefly presented face requires the ability to quickly form a discriminative representation of it. In children this should be reflected in a range of set cues (eyeglasses, beard, total shape). With development, practice, and an increasing number of faces (implied by principle C1) an overall holistic framework could develop.
5. Some of the distinct facial cues may bear a relation to the whole face, at first being an initial approximation of a facial configuration. Accordingly, the recognition is sometimes relational sometimes holistic, leading to no overall asymmetry until age ten, when an overall holistic facial configuration is accumulated.
6. Recently presented upside-down faces should not show any interaction with ordinary face recognition and no developmental change related to face recognition.
7. If the right hemisphere is the repository for the overall face schema, then damage to it should damage new face recognition.

These facts are all related to the role of the right hemisphere in the emergence of particular holistic template patterns, first for family members and friends and then a more general all-purpose configuration for the rapid representation of new faces. These facts are also the nonexceptional ones. Consider now an exceptional fact (3b), that famous faces are better recognized in the right visual field. Famous persons are characteristically known for a particular facial attribute, usually through photographs alone (for example, Yul Brynner, Howdy Doody, Will Rogers, Santa Claus, Bugs Bunny, Richard Nixon). In fact, many such personages are facially defined by their main characteristic (Brynner by baldness, Doody by freckles, Claus by a beard, Bunny by teeth and ears, Nixon by jowls). A photograph of such personages can vary widely except for that characteristic and still be recognized, which is also why professional comics can do effective imitations of famous people. Thus famous faces might well be recognized by recourse to such isolated features in relation to the whole face; such processing would by definition be better carried out by the left hemisphere.

This kind of interpretation can also explain fact 7b, that right-brain-damaged people can recognize familiar faces; ex hypothesi they do so by reference to certain isolable features of their friends' and relatives' faces (in the traumatic absence of being able to rely on their right hemisphere). They remember that grandpa is bald, grandma wears glasses, junior has freckles. Accordingly these patients can rely on metonymous relational processing for recognition of familiar faces.

These interpretations suggest that adults can recognize faces relationally. This offers an explanation for a nexus of exceptions to the developmental pattern. At about age thirteen children temporarily lose the right-hemisphere dominance for recognizing new faces (5b). Principles C and E explain this as a function of the reorganization of facial templates, based on the many new faces that a child undertakes to recognize at that age. During this period there is greater interaction between relational and holistic processing as new configurations are being formed. This would also explain the compound perception of upside-down faces (based on isolated features processed in the left hemisphere). In this view the decrease in recognition of familiar faces occurs because of the unaccustomed (and less efficient) left-hemisphere processing.

Finally, we can explain the most bizarre fact of all—that certain patients, with bilateral lesions, can recognize new faces but not old (7c). To explain this we must first recall that reciprocal inhibition of function governs the interrelation of the hemispheres. When a particular function is being carried out in one hemisphere, the same function is inhibited in the corresponding area of the other hemisphere. This mechanism explains why a skill that is overlearned in one hemisphere cannot be easily transferred to the other if the first is damaged. The healthy hemisphere inhibits the damaged one but cannot itself carry out the skill. Complementary inhibition also explains why recovery of a trained function in a damaged hemisphere can occur if the opposite untrained hemisphere is damaged. The damage to the untrained hemisphere releases the trained one from its inhibition, since both hemispheres are now damaged and neither inhibits the other. The originally trained hemisphere can now carry out some of the skill (albeit less well than an undamaged hemisphere), leading to a partial recovery of function.

Suppose, as Carey argues, that the rapid encoding of a new face depends on a highly overlearned facial configuration that is multiply interpreted in adulthood more than any single face (since every normal face implies the configuration). If only the right hemisphere is damaged, access to the general configuration is lost because of the inhibitory action of the left hemisphere. If the left hemisphere is damaged as well, the right hemisphere is released from inhibition and can carry out some of its original functions, especially the one that was most overtrained, the encoding of a new face.

In brief, if one takes the position that face recognition is a highly valued activity potentially carried out by each hemisphere in the

manner appropriate to that hemisphere, then all the stipulated facts can be explained, including those that are exceptional on the previous view that perception is an "organ" with two intrahemispheric sites[10].

We can also make predictions about new facts. One of the easiest to test would be the developmental prediction following from principle C2. Some time between two and seven children should become temporarily worse at face recognition and should also become relatively more left-hemisphered for it. This follows from the hypothesized shift from holistic to relational face processing that occurs under the impact of abruptly having to learn many new faces. Mehler (personal communication) has found some evidence related to the former prediction. Children do temporarily become less able to identify recently presented visual shapes between the ages two and seven. It remains to be seen whether this is true of face recognition in the same kind of paradigms used with adults.

The data on face recognition is consistent with the view that faces can be recognized relationally or holistically, depending on the developmental stage and neurological state of the subject. Such consistency does not disprove the view that normal adult face recognition is a right-hemisphere "organ," nor does it deny the importance of maturational factors in the development of this capacity. It does demonstrate that face recognition is not a counterexample to the main thesis of this chapter.

HOW DOES CEREBRAL ASYMMETRY COME TO EXIST?

The previous review documents the claim that the left hemisphere is dominant for relational processing and the right for holistic processing. What is the basis for this difference? The simplest answer would be the claim that it is innate in an interesting sense (as opposed to the sense in which everything about the hemispheres assumes a physiological representation). A substantive proposal is that the hemispheres process information in different ways at birth due to a direct genetically determined asymmetry that governs some physical aspect of neurological functioning. I shall call this the innate structure theory (IST).

Grosso modo IST is the only choice. How can a processing asymmetry exist without some genetically preconditioned physiological basis? The more interesting question is, What is the simplest physiological difference between the hemispheres at birth that could account for the functional asymmetries of adulthood?

The ontogenetic formation of regular relations between brain and behavior is a dynamic process of growth. The source of cerebral asymmetries must exert its influence during at least a decade while brain structures and behavioral systems emerge. Suppose the only difference between the hemispheres is that the left hemisphere is more capable during early childhood. That is, suppose that the two hemispheres function identically at birth but that the processing capacity of the left hemisphere is larger. This substantive claim, together with several other independently justified premises, is sufficient to account for the early appearance of cerebral asymmetries and their continuous development.[11] There are various models of how a quantitative asymmetry could result in the commonly observed qualitative asymmetries. The essential premises are the following.

1. Learning a relational skill involves more processing than learning a holistic skill.
2. Each hemisphere has anatomically specified cortical zones; each zone is physically predisposed to carry out certain functions, (due to its direct sensorimotor connections, functionally available cortical connections, or internal organization).
3. Any given hemispheric zone has a finite learning capacity.
4. When a skill is learned by one hemisphere the corresponding anatomical area of the opposite hemisphere is inhibited from expressing (or acquiring) that skill.
5. The left hemisphere is more powerful computationally than the right (at least during the years two to six), in the sense that it can simultaneously process a greater number of mental representations at a given maturational stage.

The first premise is a tautology and the next three premises are widely accepted.

The formal definition of the two kinds of processing automatically guarantees, *ceteris paribus*, that relational processing is more demanding than holistic. Since the formal definition of relational processing presupposes two simultaneous independent mental representations, it must be more complex than holistic processing which involves only one such representation. It is a commonplace view that intrahemispheric localization of function can be influenced by anatomical connections to other cortical areas and to particular peripheral organs. It is not controversial to suggest that, like the brain as a whole, each part of it can account for the learning of so much and no more. Contralateral hemispheric suppression of attentional processes and learning functions has received systematic experimental investigation in animals and is generally accepted for humans.[12]

The last premise is not as commonly assumed, though some arguments are plausibly consistent with it. First, systematic investigations of infant brains have brought out specific zones in which the left hemisphere is larger or more convoluted than the right at birth Recently, Corballis and Morgan (1978) have argued that a maturational gradient in favor of the left hemisphere would explain the left-hemisphere priority for language and complex motor behavior (on the assumption that they are the highest-priority skills to the exclusion of spatial organization, for example). However, they offer no independent evidence from human development. (But Brown and Jaffe (1975) and Whitaker (1978) argue that the left hemisphere matures more *slowly*.) Notice that principle 5a does not directly specify the physiological basis for the computational superiority of the left hemisphere; the left hemisphere could mature more quickly (and therefore can compute more at a time) or less quickly (and therefore is more adaptable to learning new kinds of computations).

Let us stipulate that principles 1–5 are true. Why would they lead to the observed asymmetric specialization of the left hemisphere for relational processing and the right hemisphere for holistic processing? The basic concept is that zones in the more powerful hemisphere (the left) end up carrying out the more demanding mental processes (relational). It is intuitively clear that this would occur reliably only if the acquisition of different kinds of skills is allocated to distinct brain zones (premise 2), each of which has limited capacity (premise 3). If each hemisphere had an arbitrarily large capacity, the computational superiority of the left and the relative difficulty of relational processing would be moot. Also, if there were no complementary inhibition between corresponding zones in the two hemispheres, multiple exposure of tasks would ultimately lead to bilateral representation and expression of every skill.

Still to be demonstrated is why a quantitative superiority of the left hemisphere does not predict dominance for all processing. For