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COMPUTATIONAL, GEOMETRIC, AND PROCESS PERSPECTIVES ON FACIAL COGNITION

Contexts and Challenges

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7

Faces as Gestalt Stimuli: Process Characteristics

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Whole, holistic, well-configured, Gestalt: Each of these adjectives can rather intuitively be applied to the face as a visual stimulus. But what do they mean? Although rich with history, they are somewhat bereft of precision, coming into modern usage from a scientific approach (Gestalt theory) that was based on "unquantified and ill-defined concepts of organization and form" (Uttal, 1988, p. 22). Although there have been careful attempts to move beyond this imprecision (e.g., Hochberg & McAlister, 1953; Kubovy & Pomerantz, 1981; Kubovy & Wagemans, 1995), there is still a sense that the use of these terms is, at best, undisciplined (see discussions in Kimchi, 1992; Massaro, 1998; Uttal, 1988). This is unfortunate for the study of facial cognition, as faces may be one of the most compelling examples of visual stimuli that might be described as being holistic, well-configured, or gestalt (e.g., Farah, Wilson, Drain, & Tanaka, 1998; Mermelstein, Banks, & Prinzmetl, 1979; Tanaka & Farah, 1993; Tanaka & Sengco, 1997).

The work reported in this chapter is intended as a small step toward increasing the precision associated with the notion of a face as a gestalt. In particular, we focus on the ways in which the notions of holism, configurality, and gestalts might be represented as hypotheses about the real-time characteristics of human information processing. Toward that end, we have four goals. First, we specify four general dimensions of human information processing (discussed briefly in the introductory chapter) and suggest how specific combinations of these characteristics might be used to represent the hypothesis of holistic, configural, or gestalt processing. Second, we introduce a new, dynamic approach to modeling cognitive processes in general, and apply that approach to generating predictions for gestalt and nongestalt processing. Third, we explore the coherence of this approach with existing theory on cognitive processes. Finally, we present an experimental investigation intended to provide evidence with respect to the hypotheses derived from the new and the general approach.

As we indicate later, several of the theoretical questions we pose for face processing have been asked before. For the most part, the answers have remained elusive. The following study enlists a growing methodology derived from the cognitive stochastic process theory that we and our colleagues have been developing over the past three decades. The methodology permits the testing of critical questions concerning information processing in a parameter-free environment. Equivalently, it allows the testing of large classes of models, each embedding a critical assumption, against one another. It would be premature to desire or expect instantaneous tie-ins with other approaches (e.g., neurocognitive, group-theoretic, connectionist, computational, geometric, etc.), although we hope that where appropriate, such links can be forged in future work.

DEFINING GESTALTS IN TERMS OF CHARACTERISTICS OF PROCESSING

As discussed in both the introductory chapter and elsewhere in this volume (Campbell, Schwarzer, & Massaro, chap. 8, this volume; Massaro, 1998; Thomas, 1996; Wenger, 1999, are also pertinent) the general problem of human cognition has traditionally been conceptualized either in terms of the characteristics of the information and psychological evidence or in terms of the processes that operate on that information and evidence. For the most part, we concentrate on the latter in this chapter. However, as will hopefully become apparent, the theoretical approach we describe has the ability to simultaneously represent hypotheses about information and processing. In addition, it has the potential to allow for direct connections to the types of computational models of the pattern and psychological evidence spaces that were reviewed in the introductory chapter.

As noted in that initial chapter, human information processing can be described in terms of four general dimensions: architecture, stopping rule, independence, and capacity (see Townsend & Ashby, 1983). Each of these dimensions has been the focus of decades of theoretical and empirical investigations in human cognition in general. Not surprisingly, then, these characteristics have also, with varying levels of explicitness, been of concern in investigations of facial cognition. We consider each in turn, within the context of a task requiring the detection of one or more facial features.

Consider the following hypothetical situation: You are in a crowded place, such as a mall or a conference site, and you are trying to locate a close friend you are supposed to meet. Because you know this friend quite well, you can recognize her face on the basis of very little information, such as the eyes alone. Because the area is quite crowded, this may be the only information you can acquire as you look through the crowd. Additional information, such as the nose or the mouth, is helpful but not necessary for you to perform this task.

In spite of the fact that you do not need any information beyond the minimum provided (in this example) by the eyes, we know from the current literature that providing more of the information from your friend's face, in its normal orientation and biologically appropriate configuration, will aid you in your task (e.g., Bruce, 1988, 1991; Tanaka & Sengco, 1997). This suggests that not only the sheer amount of information, but the configuration of the stimulus information, is important. This notion is bolstered by the fact that should you see your friend's face inverted in a security mirror, or distorted by the windows of a store, the increase in the amount of information available may not help you. In fact, it is possible that these violations of the facial gestalt may actually hinder your accuracy or speed.

Process Architecture

Now consider the ways in which the four general dimensions of real-time processing—architecture, stopping rule, independence, and capacity—might be used to make more precise what we mean by "gestalt." For illustration, we first consider each of the four dimensions separately, then note how combinations might be used to characterize gestalt processing. The latter suggestions are just that, of course. In each case, it is an empirical question. Also, it is important to note at the outset that our discussion here is necessarily informal; later in the chapter, the concepts are rendered with more rigor.

We begin with the dimension that has probably received the most attention in the cognitive literature, that being architecture. By *architecture* we mean the spatial and temporal arrangement of the psychological processes that are required to perform a given task. Historically, debates over architecture have focused on the distinction between parallel and serial processing (e.g., Atkinson, Holmgren, & Juola, 1969; Christie & Luce, 1956; Hamilton, 1859; Townsend, 1972, 1974, 1990a; Townsend & Ashby, 1983). More recently, a third alternative has been proposed: a parallel system in which the activations or outputs of the parallel channels are combined in a single output channel. This alternative has been referred to as *coactivation* (cf. Miller, 1982, 1986, 1991; Mordkoff & Egeth, 1993; Mordkoff & Yantis, 1991; Townsend & Nozawa, 1995); a general quantitative discussion of coactive and parallel architectures can be found in Colonius and Townsend (1997). If we consider this dimension alone, an alternative that might best capture the intuitive notion of gestalt is the coactive architecture. In our example task, one might propose a system in which the anatomical features (e.g., the eyes, nose, mouth, etc.)[1] are processed in parallel (i.e., each in its own channel). The gestalt of the face emerges as the information in each of the channels is pooled to a final output channel. In fact, in the limit the entire visible surface might converge to a nucleus of neurons with a certain pattern of firing associated with a single individual. Certain less stringent forms of parallel processing (as we note later) might also capture the notion of gestalt processing. A serial process, in contrast, in which the eyes, then the nose, then the mouth, and so forth, are processed, seems to imply a featural decomposition that is not consistent with the intuitive notion of a gestalt.

Given that there is a long history of debates on processing architecture in human information processing (see Townsend, 1990a), it is not surprising to find that theoretical distinctions based on model architecture have a significant presence in the literatures on facial perception and memory (cf. Bruce, 1988, 1991). In fact, some of the earliest inquiries into the processing of faces investigated possibilities that the constituent features might be processed sequentially or concurrently (e.g., Bradshaw & Wallace, 1971; Smith & Nielsen, 1970). However, the concern with these two candidate architectures continues in contemporary work, extending beyond consideration of the processing of facial features (e.g., in identification, discrimination, or recognition) to the processing and use of anatomical

[1] We should note that our use of the term *feature*, here and throughout the chapter, is meant to reflect the vernacular use of that term as a referent for the gross anatomical components of a face. Although it is almost certainly the case that the term is in need of a more precise and rigorous definition, we leave such work for future explorations.

features in recognition and categorization (e.g., Donnelly, Humphreys, & Sawyer, 1994; Hines, Jordan-Brown, & Juzwin, 1987; Perrett, Mistlin, & Chitty, 1987), the processing and retrieval of identity and gender information (e.g., Bruce, Ellis, Gibling, & Young, 1987) or identity and familiarity (e.g., Stanhope & Cohen, 1993), the identification and use of facial cues for emotional state (e.g., Hansen & Hansen, 1988; Nothdurft, 1993), the processing of faces (relative to inverted or distorted faces, or nonface objects) in search tasks (e.g., Donnelly et al., 1994; Kuehn & Jolicoeur, 1994; Suzuki & Cavanagh, 1995), and the testing of various computational models for face recognition (e.g., Schreiber, Rousset, & Tiberghien, 1991; Valentine, 1991; Valentine & Ferrara, 1991) and naming (e.g., Bredart & Valentine, 1992). In addition, some of these explorations have discussed theoretical notions in which component activations might be pooled, analogous to the manner of mathematical coactivation or interactive race models (cf. Bruce, Burton, & Walker, 1994; Burton & Bruce, 1992; Stanhope & Cohen, 1993).[2]

Stopping Rule

The second dimension of processing is that of stopping rule. By this, we mean the logical rule the system uses over the set of elements being processed to determine when processing can cease and a response is emitted. Two alternatives are of interest: self-terminating and exhaustive processing (e.g., Townsend & Ashby, 1983; Townsend & Colonius, 1997; van Zandt & Townsend, 1993). The first of these alternatives posits that some minimum amount of processing needs to be completed before a response can be generated, whereas the second proposes that some maximum needs to be completed before responding. In our example task, the alternative that best seems to capture the notion of gestalt processing would be the exhaustive stopping rule. Essentially, all of the stimulus information would need to (and could) be completed, perhaps as a unit, or perhaps vice versa: Because the stimulus is processed as a unitary thing, processing is a fortiori exhaustive. Here the whole of the face would be processed (rather than just some of the parts), with the gestalt emerging because of the system's exhaustive stopping rule. In contrast, a self-terminating stopping rule would only

[2] Many of the cited studies from the facial cognition literatures do not employ rigorous mathematical definitions of the various characteristics of the candidate processing systems, as we do in the work presented here. We should emphasize that, in doing so, it is not our intent to necessarily call into question the results or conclusions supplied in those earlier works; in fact, some of the results we supply are coherent with earlier conclusions. We do hope to demonstrate that it is both possible and feasible to apply precise and general formulations, in the context of powerful empirical paradigms, to a specific issue in human information processing.

allow processing to be halted once, for example, only one of the features was processed.[3] In this case, the entirety of the face is not being processed, something that seems contrary to the intuitive notion of a gestalt.

The concern with stopping rule also has an extended history in a variety of areas of research in human information processing, including facial cognition (cf. Bruce, 1988). Some of the earliest hypothesizing on stopping rules in facial cognition was done in the context of debate over the configural or featural nature of face processing (e.g., Bradshaw & Wallace, 1971; Sergent, 1984; Sergent & Takane, 1987; Smith & Nielsen, 1970; Takane & Sergent, 1983). However, the importance of considering the particular type of stopping rule is highlighted by its continuing role in a variety of investigations of facial processing (e.g., Donnelly et al., 1994; Kuehn & Jolicoeur, 1994; Stanhope & Cohen, 1993).

Process Independence

The third dimension of processing is that of process independence. By this we mean the degree to which the rate at which any one feature or element is being processed affects the rate of processing of any or all of the other elements being processed (Colonius, 1990; Townsend & Ashby, 1983; Townsend & Thomas, 1994).[4] The two alternatives of interest are simply the preservation or violation of independence in rates of processing. If independence in the rates of processing the eyes and mouth (for example) were preserved, then the speed with which the eyes might be processed would not be affected by anything (e.g., the clarity of the stimulus or its display duration) that might affect the speed with which the mouth would be processed. In our example task, the alternative that seems most consistent with the notion of gestalt processing would be a violation of independence in rates. For example, it would be possible to propose that the processing of one feature in the context of another from the same face would be facilitated. This would represent the hypothesis of a positive dependence in rates as supporting the facial gestalt. However, it is also possible that a negative

[3]P. L. Smith (personal communication, September 7, 1998) commented that although we have considered two possible situations (one in which one of n is processed, and the other in which n of n features are processed), there is a third that may be of critical interest in face processing; that is, one in which the task requires processing of $1 < m < n$ of $n > 2$ features.

[4]Ultimately, the question of dependence of speed of processing among different channels, features, dimensions, or objects in RT studies (e.g., Townsend & Ashby, 1983) must relate to dependence in accuracy over the same types of entities (e.g., Ashby & Townsend, 1986; Townsend, Hu, & Evans, 1984). The full body of relations among the RT and accuracy domains is being actively pursued in our laboratory.

dependence might be used to represent a violation of the facial gestalt. For example, it might be the case that presenting the features in a biologically inappropriate arrangement, or inverting the face, might induce a negative dependence in processing rates.

The issue of feature independence in face processing dates at least to one of the earliest and strongest suggestions that the features of a face may be processed independently (Tversky & Krantz, 1969), though possibly at varying rates as a function of perceived salience (e.g., Davies, Ellis, & Shepard, 1977; Ellis, 1975; Sergent, 1984; Shepherd, Davies, & Ellis, 1981). However, it has not always been the case that process independence has been distinguished from independence in the psychological evidence required to perform the task. Currently, the notion of interdependence of different types of perceptual and memory information for faces is playing an important role in both theorizing (e.g., Dodson, Johnson, & Schooler, 1997; Fallshore & Schooler, 1995; Farah et al., 1998; Tanaka & Farah, 1991, 1993; Tanaka & Sengco, 1997) and empirical explorations of robust (apparent) dependencies (e.g., Bartlett & Searcy, 1993; Rhodes, Brake, & Atkinson, 1993; Rock, 1988; Thompson, 1980; Yin, 1969; Young, Hellawell, & Hay, 1987). There is also evidence suggesting that it is possible, in the context of a model that allows for integration of the outputs of featural processing, to assume independence in a variety of facial processing tasks (e.g., Campbell & Massaro, 1997; Ellison & Massaro, 1997; see also Campbell et al., chap. 8, this volume).

On examining the literature, it becomes apparent that this concept is being employed by different investigators in quite different senses. Even in a single domain and theoretical approach, it is often necessary to establish several distinct forms of independence (e.g., Ashby & Townsend, 1986; Townsend & Ashby, 1983). Caution is called for when corelating results from different laboratories or approaches. The need for caution also comes from the fact that independence is very difficult to test by itself in response time (RT) studies, even though it can have a major impact on predictions. For one thing, it interacts strongly with architecture and capacity (e.g., Townsend, 1972; Townsend & Ashby, 1983).

Process Capacity

The final dimension to be considered is that of process capacity. Although the concept of capacity is a popular one in cognitive science (e.g., Kahneman, 1973; Kantowitz & Knight, 1976; Norman & Bobrow, 1975; Shiffrin, 1975, 1976), this dimension may be the one that has received the least systematic attention (although see Townsend & Ashby, 1978, 1983; Wenger & Townsend, 2000). The question of interest with respect to process capacity is the manner in which a system responds to manipulations of workload. In our example task, imagine that we can contrast performance with variations in the number of features that are visible. As we increase the number of features (i.e., as we increase the workload), one of three things can happen. If performance is unaffected (i.e., if accuracy and latency are unchanged), the system is said to exhibit *unlimited capacity* (most likely within some reasonable bounds; e.g., Fisher, 1984). If performance declines (i.e., if accuracy decreases and latency increases), then the system's performance is negatively affected by increases in workload, and the system can be referred to as having *limited capacity*.[5] Finally, if performance actually improves as a function of increasing workload (i.e., if accuracy increases and latency decreases), then the system's performance is positively affected, and the system can be referred to as being *supercapacity*. These ideas are made more rigorous later in the chapter.

The question of whether and to what extent workload affects processing efficiency can be asked with regard to different levels of processing, for instance at the level of the single feature, the channel, the object, or up to all of the entities undergoing processing. For instance, when the number of objects in short-term memory increases, a single target (e.g., a letter) is present in a Sternberg scanning paradigm, and processing is independent parallel, with each object always having the same processing time distribution, irrespective of how many objects are present, does RT increase, decrease, or remain constant over the changes in number of objects? Typically, a designation of capacity is made at the single element (e.g., letter) level and then predictions are made at more macroscopic levels; these will not typically be the same. For instance, even if capacity at the letter level is unlimited (meaning that processing speed on a single letter proceeds at the same rate no matter how many other letters are present), mean processing times for a set of independent parallel channels under an exhaustive stopping rule will increase in a negatively accelerated manner (e.g., Townsend & Ashby, 1983).

It is worth pausing to observe the kinds of interactions that can take place among architecture, channel dependencies, and capacity, although we cannot go into quantitative detail here. Consider a parallel system that is unlimited capacity at the individual object level and in which the channels

[5] A special type of capacity limitation is one in which the available processing capacity must be allocated across all the elements or features to be processed, and then remains the same without reallocation. This is a situation referred to as fixed capacity processing (Townsend & Ashby, 1983).

are stochastically independent. Then the mean minimum processing time for a set of redundant targets decreases monotonically. If those same parallel, unlimited capacity, independent channels are fused at output, rendering a coactive model, the decrease in the mean processing time is even greater than the foregoing model. However, consider a fixed capacity model, still with independent parallel channels. Then the mean minimum time is constant (e.g., Townsend & Ashby, 1983), rather than decreasing. The coactive model, with fixed capacity, will still predict a decrease in mean minimum processing time, although not, of course, as steep a decline as with unlimited capacity channels. Thus, note that capacity effects can work against (or in other cases with) the effects of a change in architecture (i.e., from ordinary parallel to coactive).

Now consider a parallel model with channels that would be simply unlimited capacity, if allowed to work alone, but with rates augmented by the other ongoing channel activity if both are working. Such a system will create positive dependencies that can eventuate an increase in overall processing speeds, such as in the mean minimum time statistic, thus resulting in supercapacity relative to that statistic, or indeed, relative to the mean processing time in each channel.

All this is pertinent, because certain of our findings point to a coactive architecture in conjunction with a moderately limited capacity system. Thus, the important thing is that although coactivation is associated with an architecture that facilitates processing speeds, its overall effects can be overcome by heavy limitations in capacity as workload increases. Also, a possible linkage with channel dependencies reappears in the Discussion.

Of the three alternatives—limited, unlimited, and supercapacity processing—the one that seems most consistent with the notion of gestalt processing is the last, at least within certain tasks, such as identification. In this case, as additional features become visible, performance would steadily improve. Having more of the face would allow the human information processor to do more faster. Unlimited capacity does not seem as close to the intuitive notion of a gestalt process, as no benefit (although no cost) is accrued as a function of having more of the face. In contrast, limited capacity processing implies a cost associated with having more of the face, something counter to the positive character of gestalt processing.

The question of capacity in face processing for the most part has been addressed only indirectly. Nonetheless, a number of research results seem to carry implications with respect to capacity. For example, reports of a face superiority effect in recognition (e.g., Homa, Haver, & Schwartz, 1976) suggest that adding facial features in their biologically appropriate configuration may aid in the recognition of a previously seen feature, relative to presentation of that feature alone (see also Farah et al., 1998; Tanaka & Farah, 1991, 1993; Tanaka & Sengco, 1997), a finding that might suggest supercapacity. Recent neurocognitive explorations seem to suggest that evidence for changes in processing capacity for faces can be found in a variety of tasks (e.g., Grady et al., 1993; Hines, Glista, & Byers, 1985; Yesavage & Jacob, 1984), with some evidence potentially supporting supercapacity processing for faces (e.g., Sergent & Corballis, 1989). Such findings are coherent with the logical expectation that some type of unlimited or supercapacity processing is most likely one of the contributors to the configurality or gestalt effects in facial cognition.

This expectation may, however, overlook at least one potentially important alternative. Assume for the moment that the human information processor is predisposed to treat faces as single, well-configured, gestalt stimuli rather than as collections of features. Now consider what might happen if such a system is presented with a task that (like many of the tasks used in explorations of facial cognition) requires the processing of some feature or set of features, possibly allowing (by task instruction or design) for self-termination on some feature. The system, predisposed as it is to processing the face as a whole (if not just exhaustively), would thus be faced with the added work of halting or attenuating its normal processing strategy to adapt to the task, a situation that could well produce decrements in performance. In this case, then, the well-configured stimulus could actually extract a cost in processing and the system could evidence limitations in capacity. The necessity of considering this possibility is reinforced by recent studies employing search paradigms, in which good configurations of features in real and schematic faces appear to be detrimental to processing efficiency and accuracy (e.g., Kuehn & Jolicoeur, 1994; Suzuki & Cavanagh, 1995).

Combinations and Tests

To this point, we have considered how the concept of gestalt processing might be represented by hypotheses about four dimensions of information processing. Considered separately, likely candidates for gestalt processing appear to be a system possessing a coactive processing architecture, an exhaustive stopping rule, violations of process independence, and supercapacity processing. However, if we consider all possible combinations of the values for the four dimensions, we can generate additional plausible candidates for representing gestalt processing.

At the outset, it seems reasonable to exclude all forms of serial processing, at least on intuitive grounds (in our later experimental work, we are careful to include tests for the possibility of serial processing). This is because serial processing, as noted earlier, seems to imply a sequential featural analysis that is not immediately consistent with the notion of a gestalt. Considering the possible variants of parallel and coactive process models, four alternatives seem closest to the notion of gestalt processing. First would be a parallel processing architecture, with an exhaustive stopping rule, in which process independence is preserved, and the system exhibits unlimited to supercapacity processing. Of course, some may find the notion of independence incompatible with a true gestalt. Second would be a parallel system, similar in all respects to the first, with the exception that process independence would be violated, probably with cross-feature facilitation. In either of these cases, all elements or features of the face would be processed concurrently, all would need to be processed before a response could be generated, and increases in the amount of facial information available would lead to improvements in performance. Additionally, in the second model, improvements in the processing of any one feature would lead to correlated improvements in the processing of the other features.

The third candidate model would be one possessing a coactive processing architecture, in which process independence (prior to the pooling of channel activations) would be preserved, with the system exhibiting supercapacity processing.[6] The final model would be similar to the third in all respects except that process independence would be violated. In both of these models, all featural information would be pooled or combined, with this aggregated information providing the sole basis for responding.

At this point, we hope we have convinced readers that it is possible to translate the inchoate notion of gestalt processing into a set of more precisely specified possibilities based on the characteristics of information processing. This is, however, a questionable accomplishment without the means of conducting strong tests among these possibilities. In particular, it would be desirable to have an experimental milieu in which hypotheses concerning the four dimensions of processing could be tested simultaneously within the performance of a single observer.

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[6]Note that because the coactive architecture holds that all channel activations are pooled to a single output channel, the distinction between self-terminating and exhaustive processing becomes moot. In addition, we should reiterate that, by definition, coactive architectures will tend toward supercapacity processing (see Townsend & Nozawa, 1995, for details).

The double factorial paradigm (Egeth & Dagenbach, 1991; Townsend & Nozawa, 1988, 1995) derives from our cognitive stochastic process theory, one that has been developing over several decades. It involves as one experimental factor (or in some cases, a set of experimental factors) that can change the processing speed of either or both of two channels (e.g., visual clarity). The other experimental factor is that of number of targets present in the display. This factor can be associated with capacity, if the object in a channel is either present or absent, as is the case in our study. The first factor requires the assumption of selective influence, the idea that a given factor affects only one designated subprocess or channel. As such, this part of the design partakes of the so-called systems factorial technology, an extensive generalization of Sternberg's (1969) additive factors method (see also Schweickert, 1978; Schweickert & Townsend, 1989; Townsend & Ashby, 1983). The assumption of selective influence is critical to the conclusions derived from experimental data (Dzhafarov, 1997; Townsend & Thomas, 1994). The second manipulation, of presence versus absence of one or more targets, can be seen as based on an extension of Donders's assumption of pure insertion (e.g., Ashby & Townsend, 1980; Luce, 1986; Sternberg, 1969; Townsend & Ashby, 1983). That is, when nothing is in a certain channel, it contributes nothing to the RT.

A schematic representation of the response regions of the double factorial paradigm, as it was implemented in this work, is presented in Fig. 7.1. The design describes a facial feature detection task (similar to the example task used in the earlier part of this chapter) in which the target features are

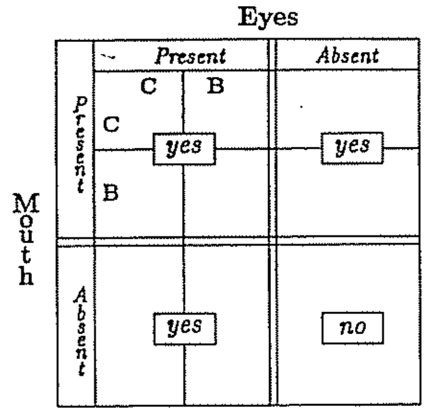

FIG. 7.1. The double-factorial paradigm, implemented as a feature detection task in which the target features (here the eyes and mouth of a face) can be present or absent. When present, the features can be clear (C) or blurred (B).

the eyes (together) and the mouth. The response rule allows participants to generate a "yes" (detection) response if they see either the eyes, the mouth, or both features in a presented stimulus.[7] Thus, the first of the factorial manipulations involves the presence or absence of target features. Participants are instructed to generate a detection response when processing either one or two features. Consequently, this level of factorial manipulation allows for collection of response data at two levels of task workload, data that are critical to assessment of system capacity (we return to the specifics of capacity measures later).

The second of the factorial manipulations is the one that is critically dependent, relative to model tests, on the assumption of selective influence. Specifically, a blurring manipulation is used such that, when either feature is present, it is present at one of two levels of feature clarity (the specifics of this manipulation are discussed later). The singular intent of this manipulation is to slow the processing of the specific feature selectively, with the effect being in force at the level of the distribution of response times. More specifically, let $F_{i,j}(t)$ be the cumulative distribution function (CDF) of RTs when the the eyes and mouth are at levels i and j, respectively ($i, j = c, b, \emptyset$ denoting the levels clear, blurred, and absent, respectively). Then, if selective influence of the clarity manipulation holds, $F_{c,j}(t) > F_{b,j}(t)$ for any fixed j and all t, and $F_{i,c}(t) > F_{i,b}(t)$ for any fixed i and all t. Note that although selective influence predicts this ordering, the ordering could obtain even if selective influence were violated. Hence, observing this ordering in data is consistent with, but does not prove, this assumption. With selective influence in effect, the four cells in the upper left quadrant of Fig. 7.1 allow for strong tests of system architecture and stopping rule (the specifics of which are spelled out later).

Dependent Measures: Architecture and Stopping Rule

As it is implemented in the work presented here, sufficient observations are collected to allow estimation of the empirical CDF per participant per cell of the design. The CDFs allow tests of system architecture and stopping rule to be conducted on an individual observer's data at the level of the mean and at the level of the distribution (Townsend, 1990b). Being able to conduct tests at these two levels allows both for converging

[7] Although the work described here allows for self-terminating processing—an OR task—the design can be implemented to require exhaustive processing—an AND task.

evidence and stronger inferences than would be possible if either were used alone.

The specific measure used to assess system architecture and stopping rule is the *interaction contrast*, a simple difference of differences that is commonly used to assess the presence and sign of an interaction in a 2×2 factorial design. As can be seen in Fig. 7.1, the four cells in the upper left quadrant comprise such a 2×2 design, where each factor (the eyes and mouth) is present at two different levels (clear and blurred). At the level of the mean, the interaction contrast takes the form

$$IC_M = \overline{RT}_{b,b} - \overline{RT}_{b,c} - \overline{RT}_{c,b} + \overline{RT}_{c,c} \tag{1}$$

This is the same form used by Sternberg (1969) in his additive factors method, as well as in extensions to more complex architectures (e.g., Schweickert, 1978, 1989). At the level of the distribution, the interaction contrast is assessed using the empirical survivor function, $S(t)$, where $S(t) = 1 - F(t)$, and the interaction contrast constructed using the survivor functions takes the form

$$IC_{SF} = S_{bb}(t) - S_{bc}(t) - S_{cb}(t) + S_{cc}(t) \tag{2}$$

Townsend and Nozawa (1995) derived distribution-free (parameter-free) predictions at the level of both the means and survivor functions for self-terminating and exhaustive versions of serial and parallel models, as well as for a class of highly interactive parallel models that subsumes the coactivation hypothesis. These predictions are summarized in Fig. 7.2. Note that the mean interaction contrast, IC_M, produces a single value with three possibilities. If $IC_M = 0$ then either a self-terminating or exhaustive version of a serial model is implicated (see Townsend & Nozawa, 1995, for the formal developments supporting these predictions). If $IC_M > 0$ then either a parallel self-terminating or a coactive model is supported. Finally, if $IC_M < 0$ then parallel exhaustive processing is indicated.

The survivor function interaction contrast, IC_{SF}, is a function that is defined across the range of the RT distribution, with four possibilities. First, $IC_{SF} = 0$ across the entire RT distribution indicates a serial self-terminating model. Second, $IC_{SF} > 0$ for all RTs suggests a parallel self-terminating model. Third, $IC_{SF} < 0$ for all RTs implicates a parallel exhaustive model. Finally, $IC_{SF} < 0$ for some $t < t'$ and $IC_{SF} > 0$ for $t > t'$ suggests either a serial exhaustive or a coactive model. In this final case, serial exhaustive processing would be implicated if the negative area were roughly equal to

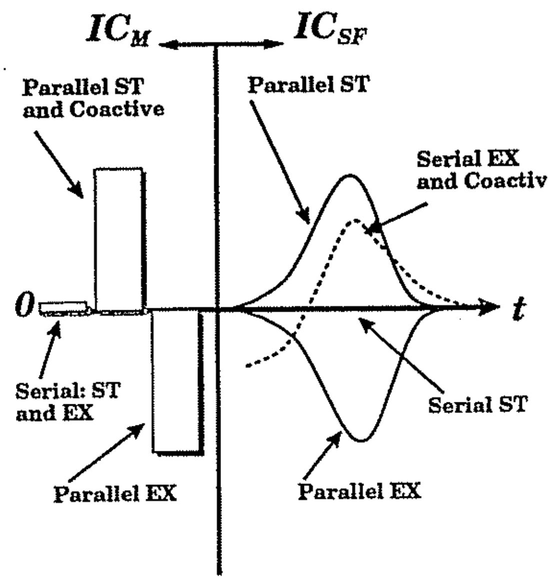

FIG. 7.2. Predictions for the interaction contrast at the level of the mean (IC_M) and survivor function (IC_{SF}). Predictions involve the four cells of the double factorial in which both features are present (see Fig. 7.1). *Note*: ST = self-terminating, EX = exhaustive.

the positive area, whereas coactive processing would be implicated if the negative area were significantly smaller than the positive area.

At this point in time, the small negative departure from positivity on the part of a coactive system's $S(t)$ contrast is not as well established globally (i.e., in as wide a variety of models) as are the signposts for the other architectures. First, that prediction was established for the general class of coactive counting models (still distribution free; e.g., not being only associated with Poisson processes), but not for all coactive models. However, it has recently shown up in all of our simulations of a fairly general set of dynamic coactive models (discussed later), so we begin to think of this feature as possibly generic to coactive models. The other aspect regards the statistical stability of this feature, which by its locus of appearance takes some of its data near the tails of frequency distributions. It has appeared in a sufficient number of data sets, though, that we are inclined to tentatively class it as nonartifactual (e.g., Nozawa, 1992; Townsend & Nozawa, 1995).

As we mentioned earlier, by using the interaction contrasts at these two levels together, it is possible to gather converging evidence and produce stronger inferences than would be possible if either were used alone. To illustrate this, assume that we examine the data and find that $IC_M > 0$. In this case, we have two models that are supported: the parallel self-terminating model and the coactive model. We then examine the survivor functions and find that $IC_{SF} > 0$ across the entire range of the RT distribution. We now have evidence that supports the parallel self-terminating model and rules out the coactive model. On the other hand, were we to have found that $IC_{SF} < 0$ for the shortest RTs while being > 0 for the longest RTs, we would have support for the coactive model, ruling out the parallel self-terminating model. Inspection of Fig. 7.2 will show that when there are multiple outcomes possible for one of the interaction contrasts, the dilemma can be conclusively resolved when the other interaction contrast is examined. We emphasize that this inferential power is possible relative to general and parameter-free representations of the candidate models, with (in the context of the double factorial paradigm) inferences supported at the level of the individual observer.

Dependent Measures: Capacity

As we noted earlier, system capacity refers to the response of a system to changes in workload. Intuitively, the notion of capacity refers to the amount of energy a system expends to accomplish its processing goals. Although the RT distribution ($F(t)$ or $S(t)$) does provide information about when processing is complete, it does not directly inform the investigator about how much energy had to be expended, in an absolute sense. However, it is possible to derive this information from a comparison of RT distributions across levels of workload (typically instantiated as number of items being worked on in a task).

To illustrate how this can be done, consider a simple task such as boiling water on a stove.[8] The processing system of interest here is the stove, and the task can be considered complete the instant the water comes to a boil. If the stove is set on high, such that a lot of energy is being expended to heat the water, then the likelihood that the water will come to a boil in the next instant should be high. In contrast, if the stove is set on low, such that only a small amount of energy is being expended, then the likelihood that the water will come to a boil in the next instant should be low. Now, by definition, the processing task is complete at the instant the water boils. Consequently, we are only interested in the likelihood of the water coming to a boil, given that it has not yet boiled.

More formally, we are interested in the conditional probability function $\frac{f(t)}{S(t)}$, where $f(t)$ is the probability density function and $S(t)$ is the

[8] We thank Lael Schooler for suggesting this metaphor.

survivor function. This conditional probability function is known as the *hazard function*, $h(t)$, and is referred to as the *intensity function* in engineering applications (see Townsend & Ashby, 1978, 1983; Townsend & Nozawa, 1995). Integrating this function up to the time at which the process completes gives the integrated hazard function, $H(t)$, a measure of the total amount of energy expended to complete the task by time t. The hazard function itself, $h(t)$, gives a measure of capacity that is even finer grained (and analogous to power; see Townsend & Ashby, 1983) than that of $H(t)$. However, the integrated hazard function appears to be a more stable statistic and is readily estimated from the data. In fact, $H(t)$ can be obtained directly from the observable RT distribution, by way of the identity $H(t) = -\ln(S(t))$. see Townsend and Ashby (1983), Townsend and Nozawa (1995), and Wenger and Townsend (2000).

This ability to directly assess capacity can be used in two ways. First, $H(t)$ can be estimated across stimulus types, holding processing load constant. In the work presented here, $H(t)$ is estimated for each stimulus type when both features are present and clear. This allows for assessment of any changes in capacity as a function of stimulus type. Second, $H(t)$ can be used to assess the system's response to changes in workload. Specifically, we can form the ratio

$$C(t) = \frac{H_{c,c}(t)}{H_{c,\emptyset} + H_{\emptyset,c}} \qquad (3)$$

called the *capacity coefficient* (derived in Townsend & Nozawa, 1995), where the numerator is the integrated hazard function for the condition in which both features are present (and clear), and the denominator is the sum of the two integrated hazard functions for the conditions in which the individual features are present separately (and clear). If the system has as much capacity for processing two co-occurring features as it does for processing the individual features separately, then this ratio will be equal to 1, and describes the situation that we earlier labeled unlimited capacity parallel processing. This result is useful specifically for the parallel self-terminating model in the context of a task allowing self-termination (i.e., an OR task) and provides a baseline for inferences regarding capacity. Specifically, if $C(t) < 1$ then the system has less processing capacity with two features together than with the features individually, corresponding to the situation we earlier labeled limited capacity. Finally, if $C(t) > 1$ then the system has more processing capacity with two features together than it does with the features individually, a situation that we earlier labeled supercapacity.

Thus, with IC_M, IC_{SF}, $H(t)$, and $C(t)$, within the context of the double-factorial paradigm, we have a complete set of measures to support inferences regarding system architecture, stopping rule, and capacity. As we have suggested, $C(t)$ provides especially significant constraints on inferences regarding system architecture. It is particularly important with respect to evidence supporting either parallel race models versus coactivation. This is because coactive systems tend toward supercapacity, all other things being equal (Townsend & Nozawa, 1995). Thus, evidence for limitations in capacity, $C(t) < 1$, would point to ordinary serial processing, limited capacity or very limited coactivation (see Townsend & Nozawa, 1997, for how unordinary serial models might mimic coactivation).

DYNAMIC MODELS FOR GESTALT PROCESSING

In this section, we describe a new method for instantiating the types of processing hypotheses just described, within the context of the double-factorial paradigm. This method is based on the tools of linear dynamic systems theory, augmented with stochastic components and decision thresholds. For simplicity, we concentrate here on developing models for varieties of parallel process architectures. However, the approach can be extended to a far wider range of possibilities (e.g., Townsend & Wenger, 1997, 1998). We also guide the reader to other specific parallel and coactive modeling approaches (e.g., Bundesen, 1990; Colonius, 1986, 1988; Diederich, 1991, 1995; Diederich & Colonius, 1991; Fisher & Goldstein, 1983; Goldstein & Fisher, 1991, 1992; Miller, 1991, 1993; Mordkoff & Yantis, 1991; Schwarz, 1996; Ulrich & Miller, 1997).

Figure 7.3 presents a schematic of the dynamic systems approach to modeling processing. In this figure, the stimulus face is composed of two features.[9] This is represented, at the left of Fig. 7.3, as a vector **u** of input values. This is the stimulus *pattern space* discussed in chapter 1. For present purposes, we model the feature inputs as step-function signals, but note that the approach allows for use of the types of formal specification of the pattern space that would be provided by computational models of the input. To each element of this input vector there is added Gaussian noise, and the combination acts as the input to a system of linear differential

[9] This is done for simplicity of presentation. In actuality, the number of dimensions can and will be much greater (see Townsend, Solomon, & Smith, chap. 2, this volume, for a related discussion).

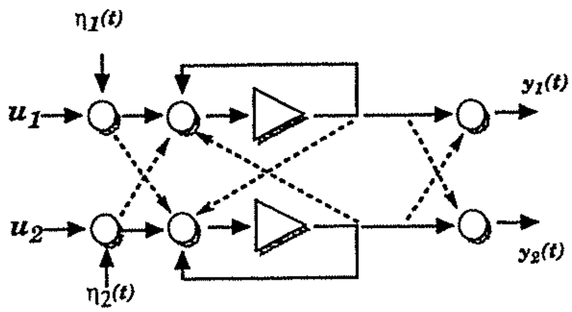

FIG. 7.3. A schematic representation of the basic linear dynamic systems framework to be used for instantiating hypotheses about process characteristics within the context of the double-factorial paradigm. Dashed lines indicate possible loci of channel cross-talk.

equations, which can be thought of as perceptual channels. The output of these channels at any point in time can be thought of as the psychological (perceptual) *evidence space* resulting from exposure to the face.

Let $\mathbf{u}(t)$ be the vector of inputs, with each component of the vector being $u_i(t)+\eta_i(t)$, or the sum of the value for the dimension and a Gaussian white noise process, respectively; $\mathbf{x}(t)$ be the vector of activations in the perceptual channels; and $\mathbf{y}(t)$ be the outputs of the perceptual channels. Let $\mathbf{A}(t)$ be an $n \times n$ matrix of rate parameters for the perceptual channels, $\mathbf{B}(t)$ be an $n \times n$ matrix of coefficients determining how the inputs will be distributed to the processing channels, $\mathbf{C}(t)$ be an $n \times n$ matrix of coefficients describing how the channel activations will be distributed to the outputs, and $\Phi(t)$ be the state transition matrix used for the solution of the differential equations. Assuming that the perceptual channels begin any trial at a resting level, that is, $\mathbf{x}(0) = 0$, the output of perceptual processing can be described as

$$\mathbf{y}(t) = \int_0^t \mathbf{C}(t)\Phi(t, \tau)\mathbf{B}(\tau)\mathbf{u}(\tau)d\tau \tag{4}$$

The specification of the models to this point captures the hypothesized process architecture. Specifically, as outlined to this point, we have a parallel process architecture, defined in dynamic terms. Now consider how we might represent hypotheses regarding the stopping rule. For the two-channel model being used for illustration, let $y_1(t)$ be the output of perceptual processing of the first feature (e.g., the eyes) and let $y_2(t)$ be the output of the perceptual processing of the second feature (e.g., the mouth). Let γ_1

and γ_2 be time-invariant criterion levels of activation required for detecting the eyes and mouth, respectively. Then, to represent the hypothesis of self-terminating processing, we would require that $(y_1(t) > \gamma_1)\,\mathrm{OR}\,(y_2(t) > \gamma_2) = (y_1(t) > \gamma_1) \vee (y_2(t) > \gamma_2)$ for the system to generate a response. Alternatively, to represent the hypothesis of exhaustive processing, we would require that $(y_1(t) > \gamma_1)\,\mathrm{AND}\,(y_2(t) > \gamma_2) = (y_1(t) > \gamma_1) \wedge (y_2(t) > \gamma_2)$.

Consideration of hypotheses regarding process independence (its preservation or violation) requires consideration of the various ways in which the processing channels might interact. As indicated in Fig. 7.3, there are three possible loci for channel interactions. The first occurs at the level of the channel inputs, and might be thought of as cross-talk in early perceptual processing. To represent process independence at this level, the $\mathbf{B}(t)$ matrix would have nonzero entries only on the diagonal. To represent a violation of independence at this level, the off-diagonal elements would be nonzero, with positive values indicating facilitative exchanges and negative values indicating inhibitory exchanges. The second possible locus of channel interactions occurs during integration of the channel inputs, and could be thought of as interactions during perceptual processing. To represent process independence at this level, the state transition matrix $\Phi(t)$ would have nonzero entries only on the diagonal.[10] In contrast, hypotheses regarding violations of process independence at this level would be represented by allowing the off-diagonal elements of $\Phi(t)$ to be nonzero. Facilitative cross-talk would involve positive values for these off-diagonal elements, and inhibitory cross-talk would involve negative values.

The final possible locus of channel interactions occurs after the channel inputs have been integrated and can be thought of in terms of simple post-perceptual interactions. To represent process independence at this level, the distribution matrix $\mathbf{C}(t)$ would have nonzero entries only on the diagonal, and violations of process independence would be represented by allowing the off-diagonal elements of $\mathbf{C}(t)$ to be nonzero. Positive values for these off-diagonal elements would represent facilitative cross-talk, and negative values would represent inhibitory cross-talk. The present set of models can be considered to be members of stochastic general recognition theory (Ashby, 1989). Using these approaches to constructing hypotheses regarding architecture, stopping rule, and process independence, and holding individual channel characteristics constant, we obtained measures of $H(t)$ and $C(t)$ for simulated systems and used those for inferring system capacity.

[10]In fact, we require that these entries all have values such that the systems constructed using this approach are asymptotically stable.

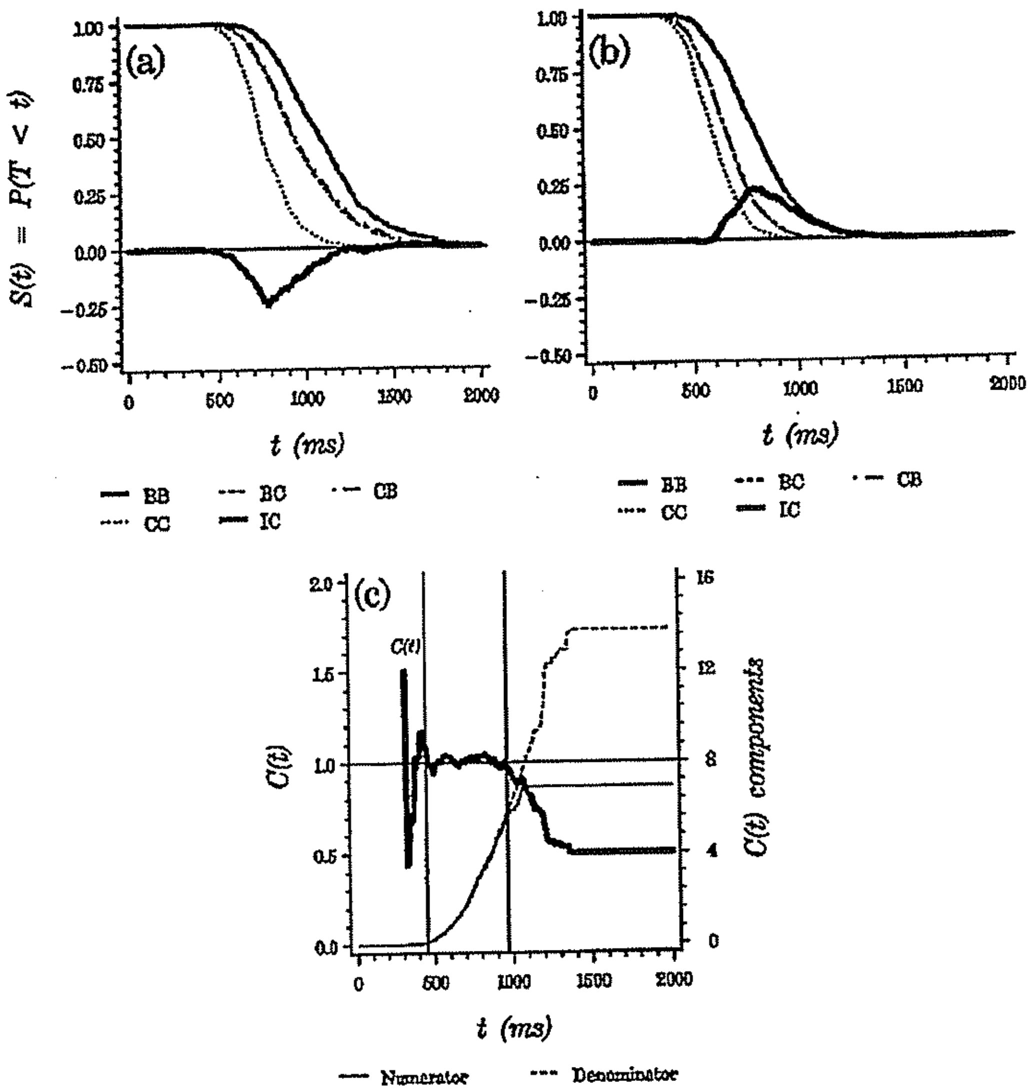

FIG. 7.4. Results of the simulation of two versions of a parallel system preserving process independence at all levels. Panel a presents the survivor functions for the double-target trials of the double-factorial paradigm, along with the survivor function interaction contrast, IC_{SF}, for the system with the exhaustive stopping rule. Panel b presents the equivalent data for the system with the self-terminating stopping rule. Panel c presents capacity coefficient $C(t)$ and its component integrated hazard functions $H(t)$ for the system with the self-terminating stopping rule.

As a basic test of the approach, we simulated two systems constructed according to this approach, assuming the double-factorial paradigm as task context. The first system considered was a parallel system, possessing process independence at all levels, and having an exhaustive stopping rule. Note that this is one of the possible representations of the gestalt processing hypothesis, although, as we observed earlier, many may find the hypothesis of independence contrary to the spirit of configurality. The second was a parallel system, also possessing process independence at all levels, and having a self-terminating stopping rule; most would agree that this combination can be thought of as representing a contrasting nongestalt processing hypothesis.

The results of this effort are presented in the three panels of Fig. 7.4. As can be seen in these panels, the results of the simulation are consistent with the general predictions derived by Townsend and Nozawa (1995). In addition (and this result is not shown in the figure), the mean interaction contrasts, IC_M, for these two systems were also consistent with the mean interaction contrasts for equivalent systems derived by Townsend and Nozawa. Thus, the basic approach is (a) flexible enough to allow the range of process possibilities corresponding to gestalt and nongestalt processing to be represented, (b) constructed in such a way that it could easily operate with pattern space inputs such as those provided by computational models (described in chap. 1), and (c) consistent with the general results obtained by Townsend and Nozawa (1995).

EXPERIMENT

With the theoretical tools of the dynamic models and the general work of Townsend and Nozawa (1995), and with the empirical tools associated with the double-factorial paradigm, we pursued two related goals. The first was to provide an initial examination of the processing of facial stimuli. We chose a feature detection task, in part because this task is one with a long history in the facial cognition literature as a source for many of the debates regarding processing characteristics with facial stimuli (for other reviews, see Bruce, 1988; Sergent, 1984), and in part because it allows a direct extension of the double-factorial paradigm from the perceptual tasks to which it has been previously applied (Townsend & Nozawa, 1995). A second goal was to provide an initial test of the set of models representing the hypothesis of gestalt processing. Our intent was to select types of stimuli that, according to a consensus in the literature, preserve or violate (in various ways) the gestalt organization or configurality of the facial stimuli. In particular, we used three stimulus manipulations (changes to a photograph of a normal face) that have been shown to produce reliable disruption of performance, relative to the processing of normal faces.

Method

Participants. A total of four individuals (members of the Indiana University psychology and cognitive science community) participated in this experiment. All four had normal or corrected-to-normal vision. Participants were compensated at the rate of $6 per session.

Materials and Apparatus. Four different stimulus types were used (see Fig. 7.5). The first of these provided a baseline for comparison, with respect to effects of configurality of gestalt organization. This first stimulus (Panel a in Fig. 7.5) was a frontal view of a white man centered on a gray background. The width and height of the face were 2.4 cm and 3.4 cm, respectively, and the width and height of the background were 4.8 cm and 3.8 cm, respectively. The baseline face (which we refer to

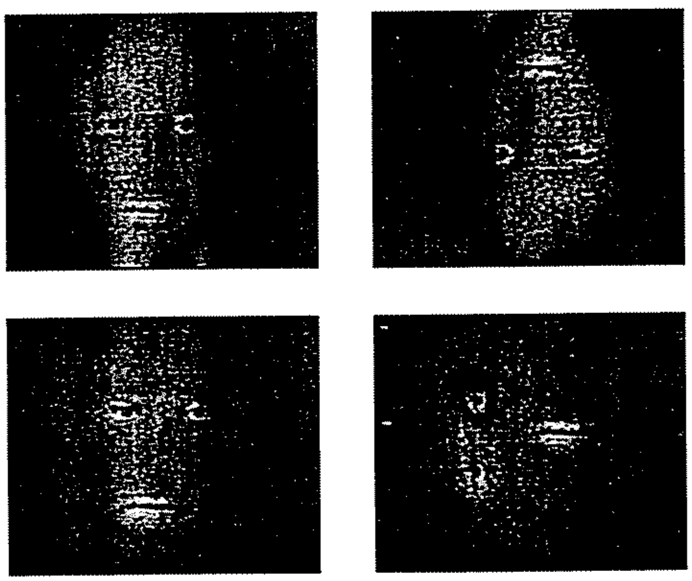

FIG. 7.5. The four stimulus types used: (a) normal upright face, (b) inverted version of the normal face, (c) the target features in their normal positions with the facial surround removed, and (d) the target features in nonstandard (scrambled) positions.

as the *normal* face) was constructed from the original photograph by first applying a Gaussian blur (using Aldus Photostyler) such that only the contours of the original face were visible. The target features from the original photograph (the eyes and mouth) were then pasted onto this "base" face and the edges of the pasted regions were averaged with the surrounding area to remove any lines or visual discontinuities. The second stimulus (Panel b in Fig. 7.5) was simply the first stimulus inverted, a manipulation that has been demonstrated to produce robust disruption of effects associated with processing normal upright faces (e.g., Carey & Diamond, 1994; Diamond & Carey, 1986; Rhodes et al., 1993; Yin, 1969). We refer to this stimulus as the *inverted* face.

The third stimulus (Panel c in Fig. 7.5) was constructed with the intent of isolating the target features from the baseline face. This was done by taking 0.6 cm-high strips, centered about each of the target features, running the entire width of the background. These strips were positioned to preserve the absolute and relative placement of the target features from the baseline face, and the regions of the face outside the strips were replaced with a uniform gray of the same darkness as the background to the face. By isolating the target features within strips, we were able to maintain the local differences in contrast around the target features while removing the facial surround, the latter being a manipulation that has reliably been shown to produce effects suggesting disruption of the facial gestalt (e.g., Tanaka & Farah, 1991, 1993; Tanaka & Sengco, 1997). In the presentation and discussion to follow we refer to this stimulus as the *feature* face.

The fourth stimulus (Panel d in Fig. 7.5) was designed with the intent of producing the most profound disruption of processing that might produce gestalt or configural effects. This stimulus was constructed from the third stimulus (Panel c) by rotating the strip containing the eyes 90° clockwise and moving it to the location of the left boundary of the face, and moving the strip containing the mouth 1.5 cm up from its original position with its leftmost edge at the location of the right boundary of the face. When observers were presented with this stimulus type, the features were always in these locations. These two changes disrupted both the top-down ordering and left–right symmetry of features, two manipulations that have been shown to produce disruptions of the normal processing of facial stimuli (e.g., Kuehn & Jolicoeur, 1994). We refer to this stimulus as the *scrambled* face.

In addition to these stimuli, a fixation cross was constructed using the background to the base face, with a black cross placed on the background. The dimensions of the background for the fixation cross were identical to those of the background for the faces, and the cross itself was centered at the point where the tip of the nose of the intact face would have been.

The stimuli (including the fixation cross) were mounted (centered) on white cards and presented tachistoscopically, using a Gerbrands four-field tachistoscope controlled by a PC-compatible microcomputer, which also recorded observers' responses and their latencies. Observers responded using an eight-button response box. Display durations and recorded RTs were accurate to ± 1 msec. At a viewing distance of 79 cm, the faces subtended 1.8° and 2.5° of visual angle (horizontally and vertically, respectively), whereas the background subtended 3.5° and 2.8° of visual angle (horizontally and vertically, respectively). The luminance levels in each of the fields—1.05 cd/m^2—were selected on the basis of pilot work, to allow for near-perfect levels of accuracy with a minimum of participant fatigue.

Procedure. Participants were tested for a minimum of 65 sessions,[11] with each session lasting approximately 1 hr. Participants, on average, attended five sessions per week. Excepting illness, holidays, equipment malfunctions, and personal requirements, no more than 2 days elapsed between successive sessions. Each session began with the observer dark adapting for at least 5 min. Following this, four blocks of trials, each consisting of 96 trials, were run. Blocks were composed of a single stimulus type (normal, inverted, feature, or scrambled) and ordering of the stimulus types was done according to a balanced Latin square.

Work exploring the redundant targets effect (e.g., Mordkoff & Egeth, 1993; Mordkoff & Yantis, 1991), has noted that the benefits that can be observed with redundant targets need to be distinguished from the benefits that can accrue because of statistical contingencies among different stimulus types. These contingencies (referred to as interstimulus and nontarget contingency benefits) are both a function of trial frequency. With this in mind, trial frequencies were selected such that both of these contingencies were null.

Each trial began with a short tone (440 Hz for 250 msec) being sounded coincident with the presentation of the fixation cross, which remained visible for 1 sec. Following this, the stimulus was illuminated for 75 msec. Observers responded by pressing a button with the index finger of their dominant hand to indicate the perceived presence of either or both of the target

[11]The total number of sessions differed for each participant, for a variety of reasons, including scheduling conflicts, equipment malfunctions, and so on. Observers 1 and 2 participated for 65 sessions each, Observer 3 participated for 74 sessions, and Observer 4 participated for 73 sessions.

features, and pressing a button with the index finger of their nondominant hand to indicate the perceived absence of both features. Feedback about the accuracy of each response was given immediately following the response, with a short (100 msec) tone being sounded to indicate whether the response was correct (880 Hz) or incorrect (220 Hz). A constant 3.5-sec intertrial interval followed the feedback. At the end of each block, participants were given feedback concerning their overall accuracy and latency, with participants being instructed to optimize on both dimensions simultaneously.[12]

Results

The initial five blocks of trials for each stimulus type for each observer were discarded as practice data. For the remaining data, overall accuracy levels for all observers on all stimulus types were above 93%. As the primary data of interest here are the patterns in the RTs (although see Nozawa, Hughes, & Townsend, 1997, for complementary findings in accuracy), we make no further mention of the accuracy data. Analyses of the RT data were restricted to trials on which correct responses were made, and all analyses were carried out at the level of the individual observer. Unless otherwise noted, all results reported were significant at an alpha level of .05.

Analysis of Mean RTs. Although, for present purposes, the crucial analyses are those examining the interaction contrasts and measures of processing capacity, we begin by presenting an overall analysis of variance (ANOVA) to provide a global summary of the observed patterns, with a particular focus on those four trial types on which both target features were present. To provide the most stable estimates of mean latency, data were aggregated across eight successive blocks to produce a meta block. A 16 (metablock: 1–16) $\times$ 2 (eyes: clear, blurred) $\times$2 (mouth: clear, blurred) ANOVA was conducted for each stimulus type for each observer. For brevity, we refer to the meta-block, eyes, and mouth factors as B, E, and M, respectively. The data entered into these analyses are presented in the four panels of Figs. 7.6 through 7.9.

[12]Early in their participation, Observers 3 and 4 showed pronounced speed–accuracy trade-offs for all of the stimulus types. To correct this, the experimenter instructed these observers to optimize for accuracy initially and, when accuracy improved and stabilized, then instructed the observers to optimize both speed and accuracy. In addition, for particular trial types in which the trade-off was pronounced, observers were given the chance to repeatedly view the problematic stimuli in between blocks. Blocks in which such problems were documented were excluded from analyses.

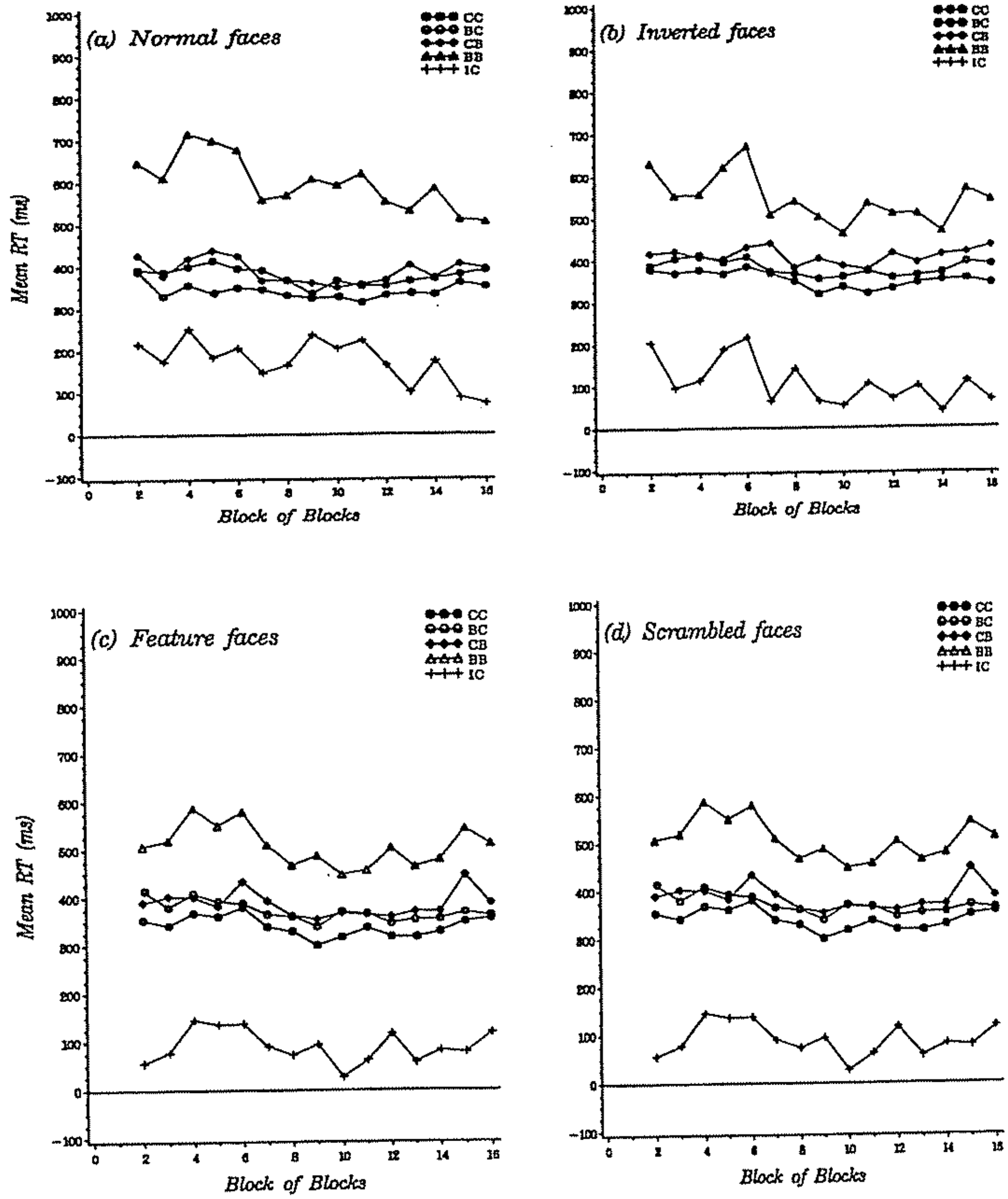

FIG. 7.6. Mean latency for each of the four trial types for each of the four stimulus types for Observer 1 across metablocks of trials: (a) normal (baseline) faces, (b) inverted faces, (c) feature faces, and (d) scrambled faces. Also presented is the mean interaction contrast—IC_M—for each stimulus type across metablocks.

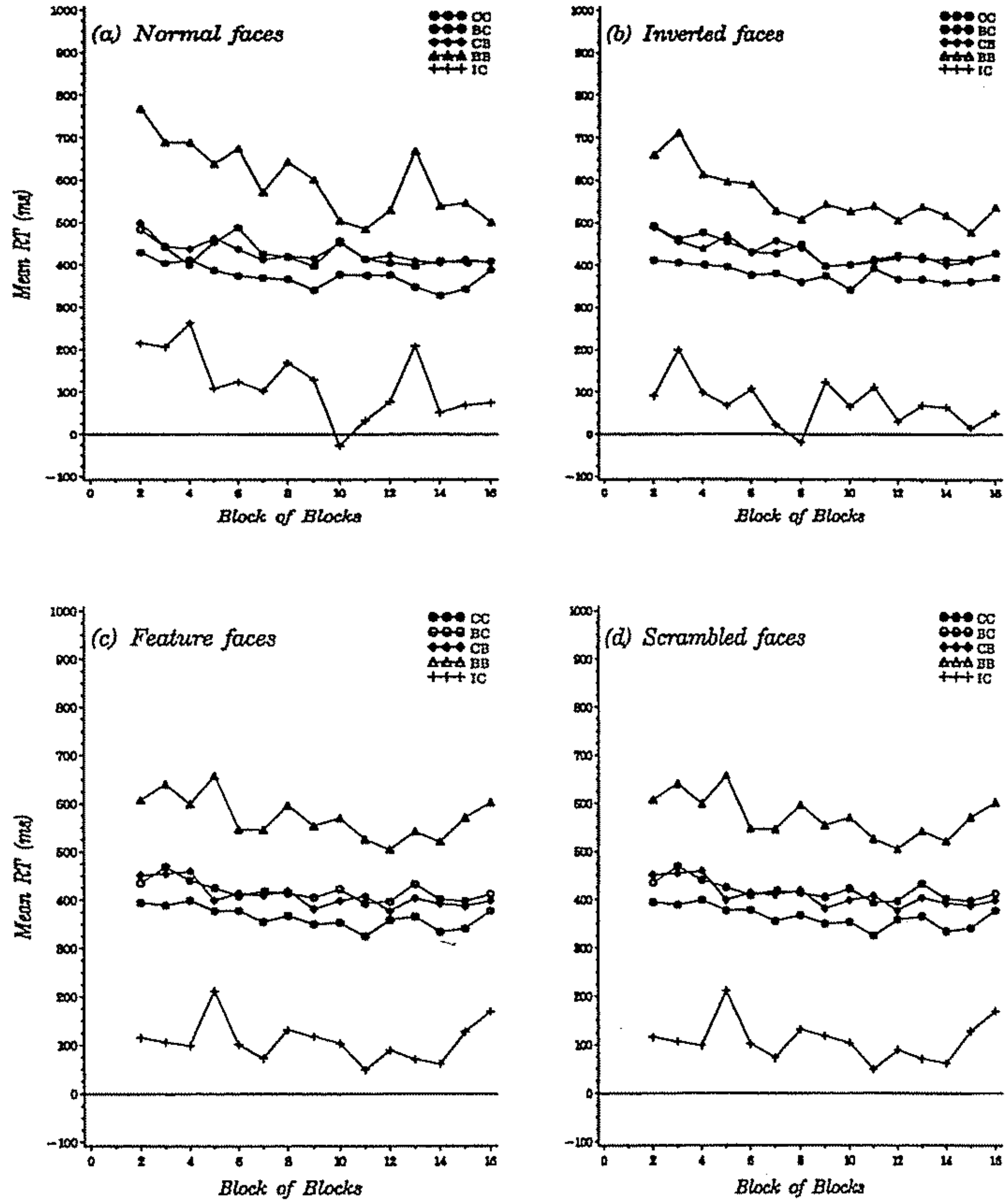

FIG. 7.7. Mean latency for each of the four trial types for each of the four stimulus types for Observer 2 across metablocks of trials: (a) normal (baseline) faces, (b) inverted faces, (c) feature faces, and (d) scrambled faces. Also presented is the mean interaction contrast—IC_M—for each stimulus type across metablocks.

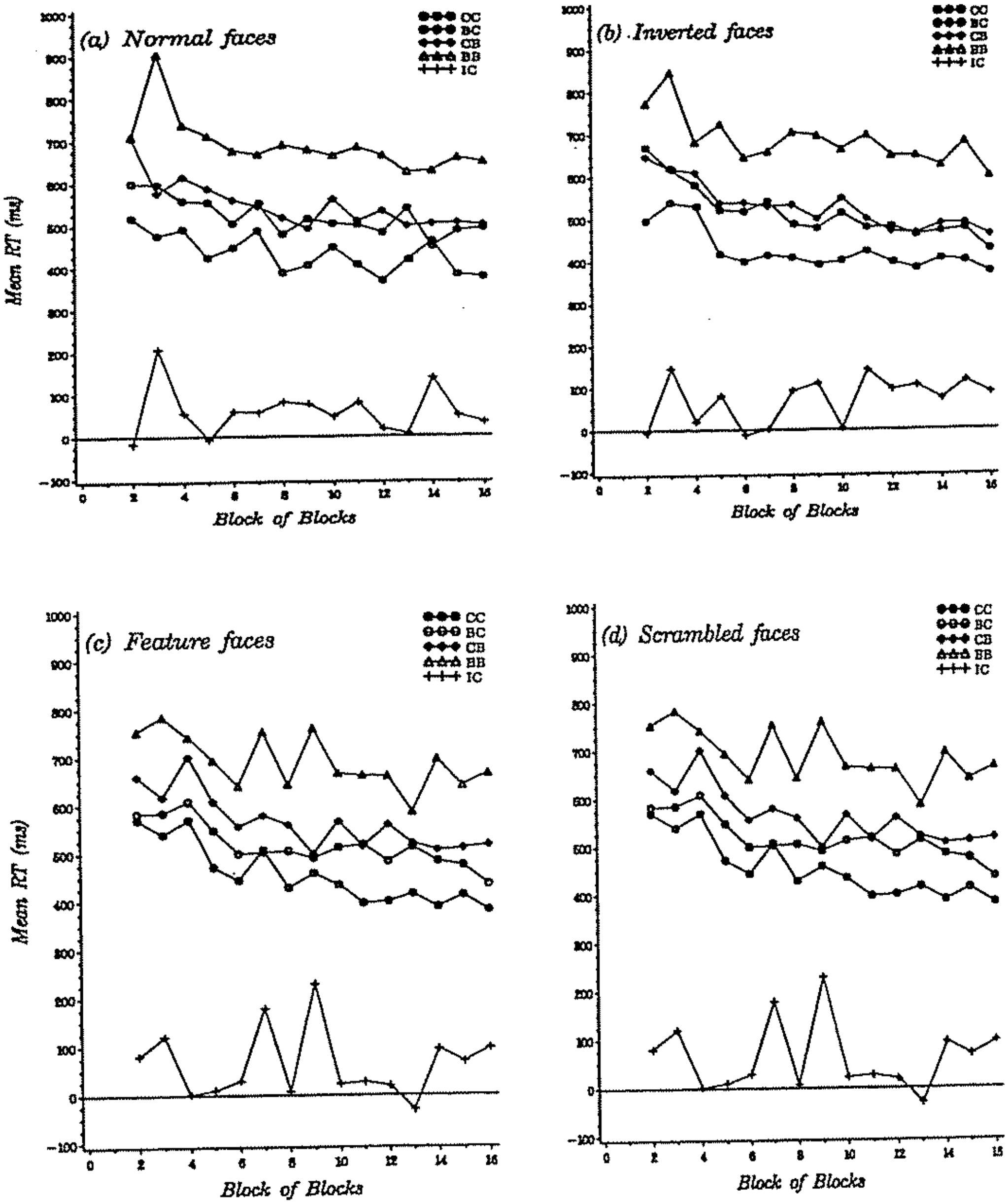

FIG. 7.8. Mean latency for each of the four trial types for each of the four stimulus types for Observer 3 across metablocks of trials: (a) normal (baseline) faces, (b) inverted faces, (c) feature faces, and (d) scrambled faces. Also presented is the mean interaction contrast—IC_M—for each stimulus type across metablocks.

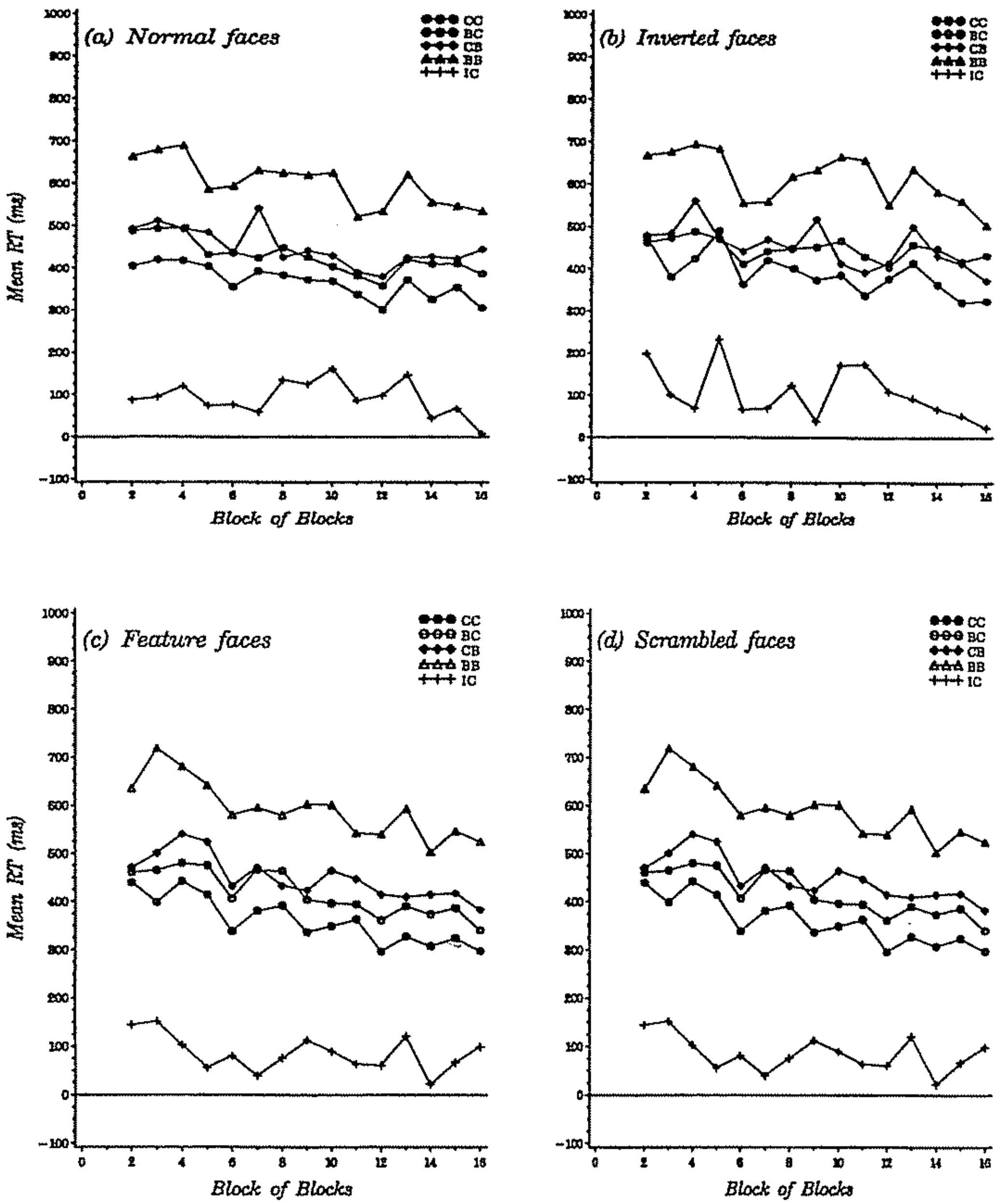

FIG. 7.9. Mean latency for each of the four trial types for each of the four stimulus types for Observer 4 across metablocks of trials: (a) normal (baseline) faces, (b) inverted faces, (c) feature faces, and (d) scrambled faces. Also presented is the mean interaction contrast—IC_M—for each stimulus type across metablocks.

TABLE 7.1
ANOVA Results for Each of the Four Observers for Each of the Four Stimulus Types

		O_1	O_2	O_3	O_4
Normal faces					
Meta-block (B)	F	8.09	9.13	9.97	13.29
	MSE	33153.47	33987.68	73107.97	93893.18
Eyes (E)	F	335.87	181.75	429.14	561.05
	MSE	2915712.54	776472.11	3147147.08	3962663.19
$B \times E$	F	2.91	2.05	ns	ns
		11920.23	8745.60	—	—
Mouth (M)	F	351.97	300.79	314.98	397.44
	MSE	2261687.45	1285052.39	2309916.94	2807094.28
$B \times M$	F	2.82	2.42	ns	ns
	MSE	11534.59	10324.71	—	—
$E \times M$	F	344.88	121.90	11.71	75.57
	MSE	1413145.53	520795.60	85901.70	533782.64
$B \times E \times M$	F	2.32	2.52	ns	ns
	MSE	9500.40	10776.91	—	—
Inverted faces					
Meta-block (B)	F	6.43	8.71	12.74	9.14
	MSE	25928.51	22816.72	88297.60	78948.80
Eyes (E)	F	471.43	173.88	388.90	327.40
	MSE	1901090.35	655174.00	2695247.70	2837612.10
$B \times E$		ns	ns	ns	ns
Mouth (M)	F	278.08	267.98	404.10	310.43
	MSE	1121383.29	1009767.65	2800555.22	2682373.00
$B \times M$	F	2.24	ns	ns	ns
	MSE	9041.18	—	—	—
$E \times M$	F	142.94	52.40	25.94	62.69
	MSE	576431.71	197429.86	179799.07	541711.60
$B \times E \times M$	F	2.61	ns	ns	ns
		10528.94	—	—	—
Feature faces					
Meta-block (B)	F	7.66	5.70	18.54	16.49
	MSE	33181.84	25011.65	11685.51	110530.21
Eyes (E)	F	340.93	270.84	528.51	357.91
	MSE	1476176.32	1189048.49	3331570.68	3739954.05
$B \times E$	F	ns	ns	ns	ns
Mouth (M)	F	259.58	407.95	217.72	332.07
	MSE	1123935.30	1790970.80	1372466.81	2226077.82
$B \times M$		ns	ns	ns	ns
$E \times M$	F	96.79	112.61	16.12	56.58
	MSE	419069.21	494378.87	101584.80	379281.66
$B \times E \times M$	F	ns	ns	ns	ns
Scrambled fuces					
Meta-block (B)	F	8.87	5.87	24.59	25.48
	MSE	37144.59	27875.37	174472.04	143681.01
Eyes (E)	F	309.45	255.91	241.65	311.68
	MSE	1296156.31	1215759.66	1714358.84	1757576.27
$B \times E$	F	3.28	ns	ns	ns
	MSE	13722.55	—	—	—
Mouth (M)	F	434.59	388.97	457.22	397.56
	MSE	1847879.47	1820290.76	3243763.62	3369697.81
$B \times M$	F	ns	ns	ns	ns
$E \times M$	F	99.38	46.69	12.87	21.56
	MSE	416257.04	221792.56	93319.90	121592.13
$B \times E \times M$	F	ns	ns	ns	ns

The main results of the ANOVAs are summarized in Table 7.1. Although the main effects of the clarity manipulations on each of the features (as well as their interactions) are of critical interest, the possible manner in which these effects might have changed across the experimental experience must also be considered. The main effect for metablock was significant for all observers and all stimulus types. As can be seen in Figs. 7.6 through 7.9, mean RT decreased somewhat across metablocks, evidencing an unsurprising effect of practice with the stimuli. However, this effect of practice could be critical should it affect the main effects and (in particular) the interactions associated with the clarity manipulations. As can be seen in Table 7.1, in most cases the interaction of metablock with the individual clarity manipulations was nonsignificant. Exceptions were as follows: For the normal faces, Observers 1 and 2 showed significant $B \times E$ and $B \times M$ interactions; for the inverted faces, Observer 1 showed a significant $B \times M$ interaction; and for the scrambled faces, Observer 1 showed a significant $B \times E$ interaction. For each of these exceptions, the form of the interaction was such that the magnitude of the pertinent main effect (summarized later) was decreased across metablocks. Finally, the three-way interaction of metablock, eye clarity, and mouth clarity was nonsignificant in most cases, with exceptions obtained for Observers 1 and 2 for the normal faces, and Observer 1 for the inverted faces. For each of these exceptions, the effect of this three-way interaction was to attenuate the sign (but not change the sign; see later) of the interaction of eye and mouth clarity. In sum, although there were distinct effects of experience for all observers and all stimulus types, it does not appear that those effects in any way compromised the interpretation of the data relative to the two clarity manipulations.

We can now consider, at least at the coarse level afforded by the ANOVA, the effects associated with the clarity manipulations. A first question is whether these manipulations produced their intended effects: Did the clarity manipulation allow us to reliably slow processing of each of the features for each of the stimulus types? Inspection of Table 7.1 shows that the clarity manipulation was reliable for both features, across all observers and stimulus types. The means pertinent to each of these main effects are summarized (collapsed across metablocks) in Table 7.2. The data thus strongly suggest that the clarity manipulations did have the intended effect of slowing the processing of the eyes and mouth for all observers and all stimuli.

Noting this, we can now examine the nature of the interaction between the two features. As can be seen in Table 7.1, the interaction between eye clarity and mouth clarity was significant for all observers and all stimulus types

TABLE 7.2
Mean Response Times (in msec) for Each of the Four Observers (Collapsed Across Metablocks) as a Function of the Clarity of the Target Features for Each of the Four Double Target Stimulus Types

Feature	*Level*	O_1	O_2	O_3	O_4
Normal faces					
Eyes	Clear	359	402	468	394
	Blurred	463	470	590	520
Mouth	Clear	364	402	479	405
	Blurred	456	468	570	509
Inverted faces					
Eyes	Clear	367	404	463	413
	Blurred	462	467	576	523
Mouth	Clear	380	403	469	417
	Blurred	444	468	566	519
Feature faces					
Eyes	Clear	355	390	476	385
	Blurred	439	468	608	508
Mouth	Clear	362	386	497	400
	Blurred	430	471	571	493
Scrambled faces					
Eyes	Clear	359	394	492	397
	Blurred	437	473	584	480
Mouth	Clear	355	390	481	383
	Blurred	443	480	600	495

types. This interaction is summarized by the mean interaction contrast described earlier, and the values of this contrast are displayed (by metablock) for each observer and stimulus type in Figs. 7.6 through 7.9. As shown in these figures, the mean interaction contrasts were consistently positive, with some attenuation as a function of practice and a minority of cases (29 of 256) in which the interaction contrast was not significantly different from 0.[13] The reliability of these positive values was assessed using one-tailed *t* tests, comparing the value of the interaction contrast to 0. These tests

[13]For Observer 1: Metablock 2 for the scrambled faces. For Observer 2: Metablocks 10 and 11 for the normal faces; 7, 8, and 15 for the inverted faces; and 9, 11, and 14 for the scrambled faces. For Observer 3: Metablocks 2, 5, 12, and 13 for the normal faces; 2, 4, 6, 7, and 10 for the inverted faces; 6, 7, 10, 11, and 13 for the feature faces; and 2, 6, and 11 for the scrambled faces. For Observer 4: Metablock 16 for the normal faces; 2 and 13 for the scrambled faces.

showed that across metablocks and for all observers and stimulus types, the positive interaction contrasts at the level of the mean were reliable.

The implication of this result is that we can now effectively rule out all forms of serial processing and all exhaustive processing (see Fig. 7.2) for all four stimulus types and all four observers. Instead, at this level of analysis, the data support either parallel self-terminating processing (a horse-race model) or coactivation. These conclusions are consistent with the conclusions reached in previous work with far simpler and far less configural stimuli (Townsend & Nozawa, 1995). Consequently, these results raise the question of the degree to which the processing made manifest by our stimuli corresponds to the processing that would otherwise be associated with the processing of facial stimuli.[14]

One possible way of addressing this question is to examine performance across the different stimulus types. To the degree that observers are treating these stimuli as, for example, simple collections of forms, rather than faces, one would predict an absence of differences in RT as a function of stimulus type, particularly for the double-target trials on which both features were clear. These would be the trials that, should there be an absence of a difference between the normal faces and the other stimulus types, would provide the strongest evidence in support of the contention that the processing of these stimuli did not reflect anything particular to faces per se.

Table 7.3 presents the mean RTs for these trials for each of the different stimulus types for each of the four observers. A one-way ANOVA conducted on these data for each observer indicated a reliable difference in RTs as a function of stimulus type; $F(3, 910) = 6.79$, $MSE = 2199.84$ for Observer 1; $F(3, 894) = 3.41$, $MSE = 3965.20$ for Observer 2; $F(3, 922) = 4.24$, $MSE = 9067.73$ for Observer 3; and $F(3, 1009) = 6.21$, $MSE = 7623.27$ for Observer 4. Tukey comparisons indicated that, for all observers, RTs were reliably slower for inverted faces than for normal faces.

[14]Of late, it has been noted that serious consideration needs to be given to the distinction between the processing of faces and the processing of representations of faces (e.g., Read, Vokey, & Hammersley, 1990; Vokey & Read, 1992). There are numerous potential implications of this distinction, not the least of which echoes the calls and concern for ecological validity in a variety of domains within cognitive psychology (e.g., Banaji & Crowder, 1989; Ceci, & Bronfenbrenner, 1991; Neisser, 1988). Although we share many of the concerns voiced in this debate, we have chosen to pursue the questions of interest using a standard experimental approach with static representations. We have striven to create materials that are as realistic as possible within the constraints of the experimental preparation, and would point out that, visually, our materials are at least as good as the standard materials in the literature, materials that have supported a very fruitful research enterprise. In addition, we would point out that our approach to stimulus construction varies little from the modal approach used in studies of facial perception and memory.

TABLE 7.3
Mean Response Times for the Double-Target Trials (Both Features Clear), Averaged Across Metablocks, for Each of the Different Stimulus Types for Each of the Four Observers

Stimulus Type	O_1	O_2	O_3	O_4
Normal faces	375	340	423	364
Inverted faces	387	353	443	438
Feature faces	363	339	438	346
Scrambled faces	362	324	415	341

In addition, for Observers 1, 2, and 4, RTs were reliably faster for feature and scrambled faces than for normal faces. For Observer 3, RTs were reliably faster for scrambled than for normal faces, and there was no reliable difference in latencies between normal and feature faces. Thus, we obtained a decrement in performance as a function of inversion, obtaining a benefit as a function of preserving the facial gestalt, relative to at least one other stimulus type. This pattern of costs and benefits as a function of the configural nature of the stimulus is a theme to which we frequently return.

Analysis of RT Distributions. As we mentioned at the outset, the conclusions possible on the basis of the mean interaction contrasts can be constrained by examination of the survivor function interaction contrasts. For our purposes, we are most concerned with evidence that might preferentially support either parallel self-termination or coactivation.

Figures 7.10 through 7.13 present the survivor functions, $S(t)$, and survivor function interaction contrasts, IC_{SF}, for each of the four double-target trial types for each of the four observers. Before examining the form of the interaction contrast, however, we need to determine whether the survivor functions themselves are ordered as would be predicted by the clarity manipulations: $S_{bb}(t) > S_{bc}(t)$, $S_{cb}(t) > S_{cc}(t)$. Violation of this ordering would make it difficult (perhaps impossible) to interpret the interaction contrast.

Kolmogorov–Smirnov tests were conducted on all possible pairings of the survivor functions for each of the stimulus types for each observer.[15]

[15]Note that, for practical purposes, these tests were conducted at the level of the empirical CDF,

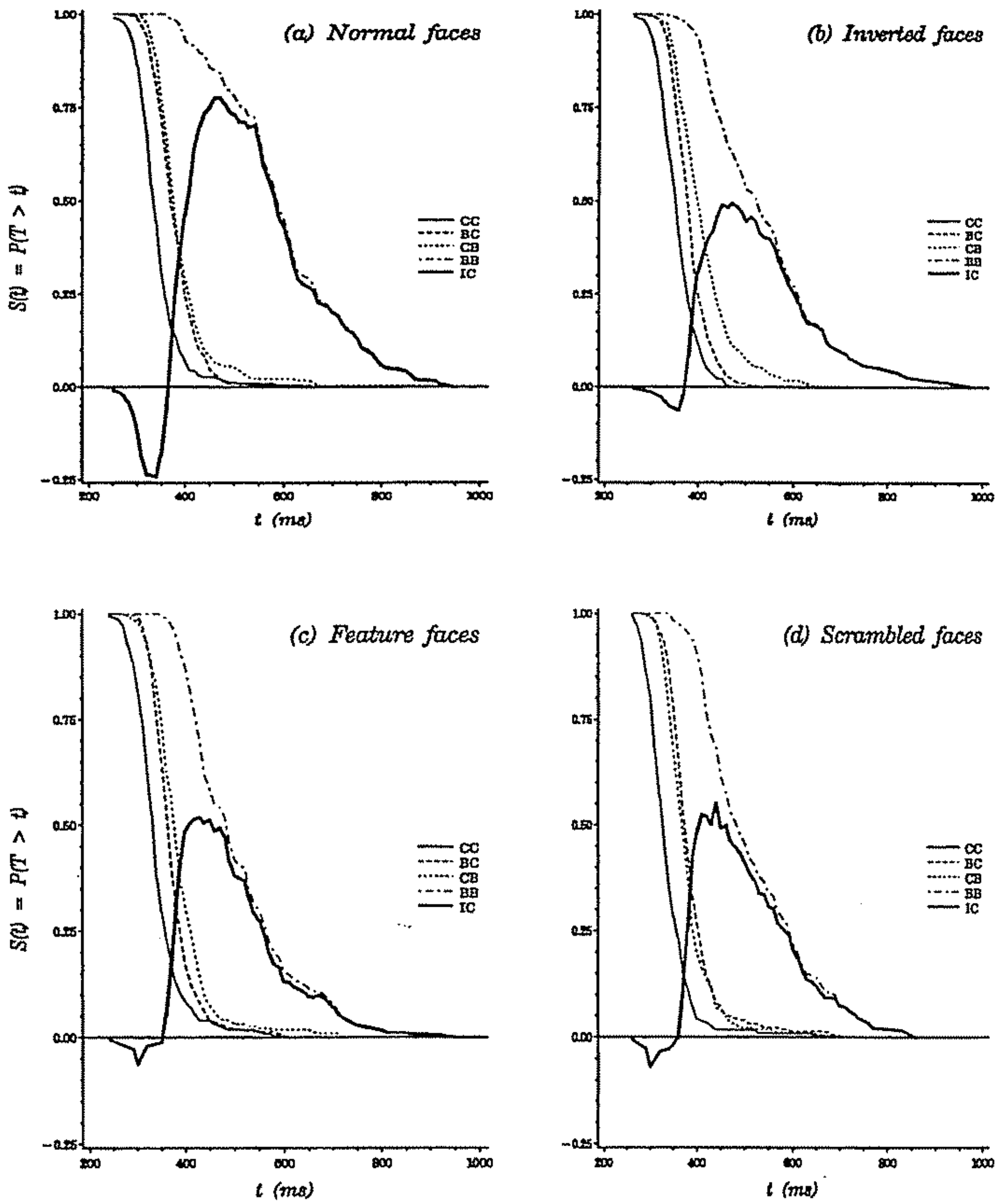

FIG. 7.10. Survivor functions, $S(t)$, and survivor function interaction contrasts—IC_{SF}—for the four double-target trial types for each of the four stimulus types for Observer 1: (a) normal faces, (b) inverted faces, (c) feature faces, and (d) scrambled faces.

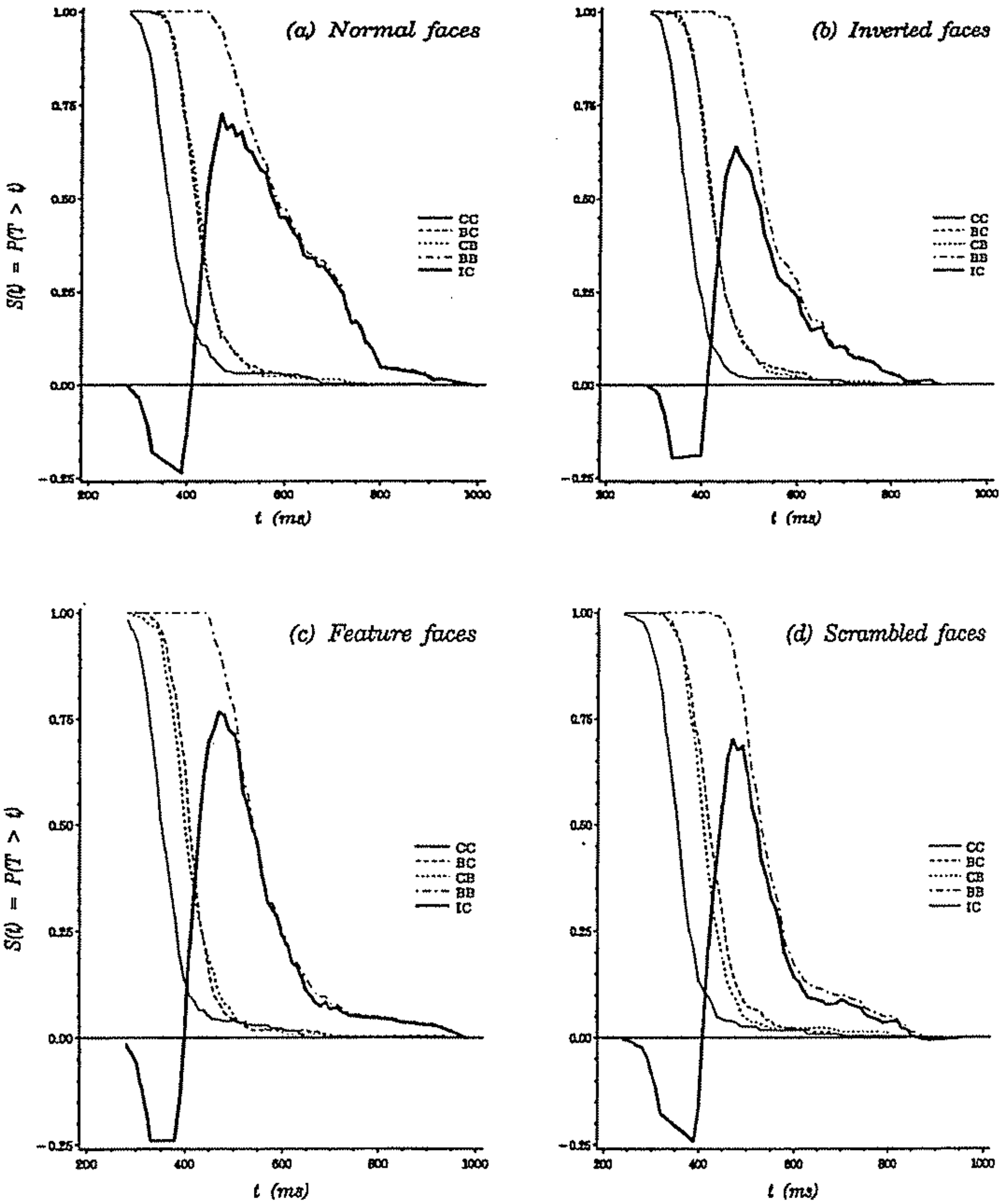

FIG. 7.11. Survivor functions, $S(t)$, and survivor function interaction contrasts—IC_{SF}—for the four double-target trial types for each of the four stimulus types for Observer 2: (a) normal faces, (b) inverted faces, (c) feature faces, and (d) scrambled faces.

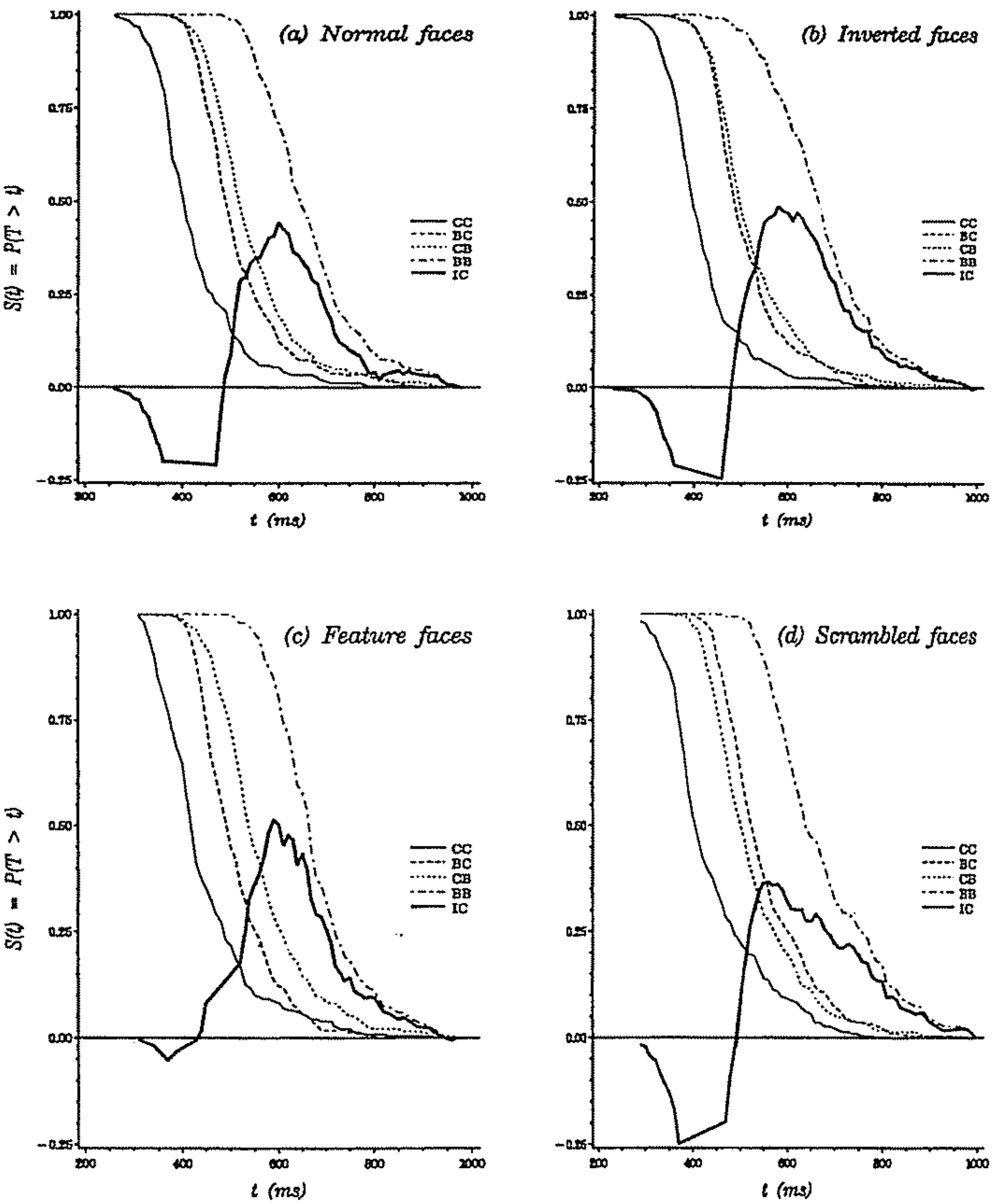

FIG. 7.12. Survivor functions, $S(t)$, and survivor function interaction contrasts—IC_{SF}—for the four double-target trial types for each of the four stimulus types for Observer 3: (a) normal faces, (b) inverted faces, (c) feature faces, and (d) scrambled faces.

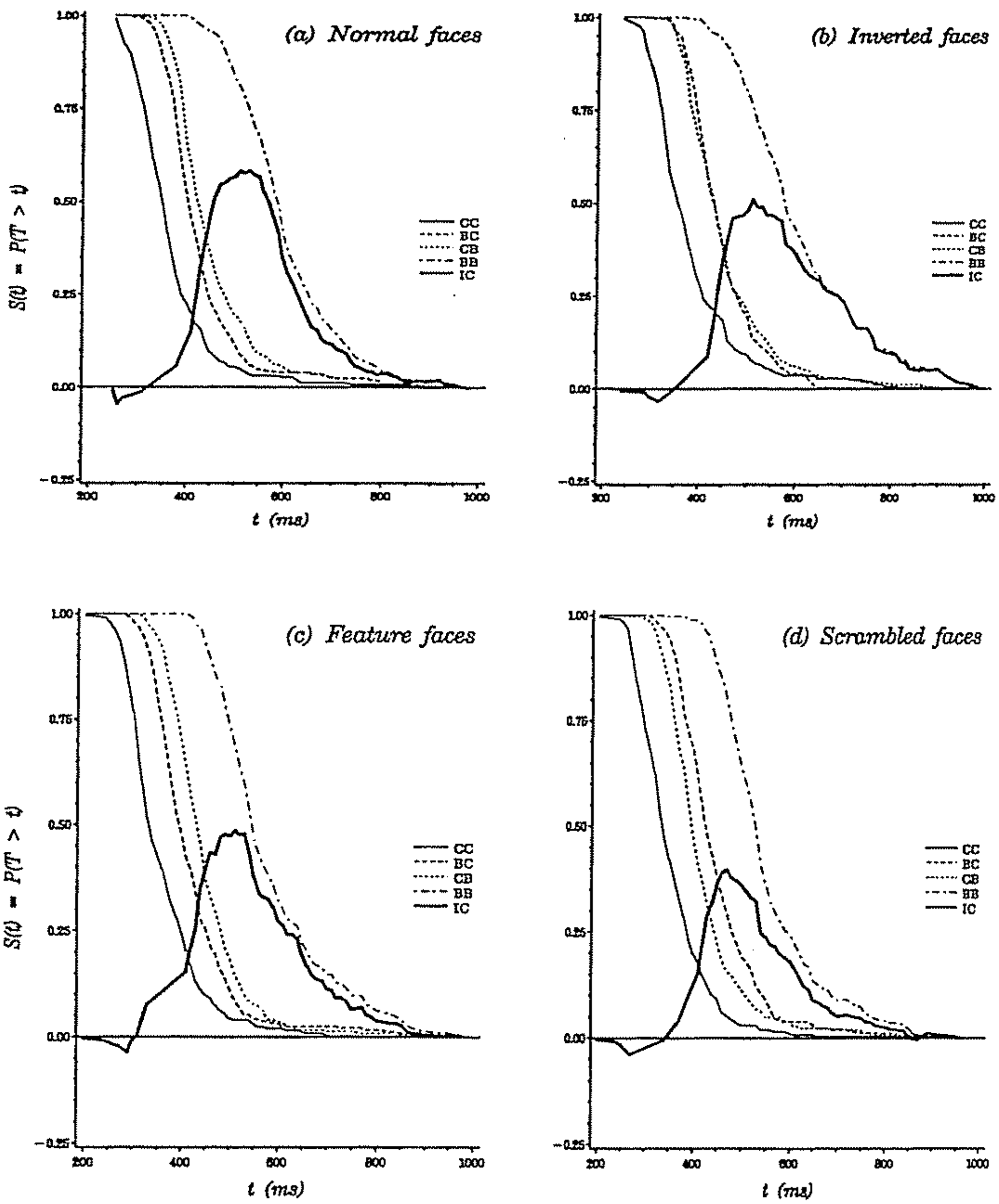

FIG. 7.13. Survivor functions, $S(t)$, and survivor function interaction contrasts—IC_{SF}—for the four double-target trial types for each of the four stimulus types for Observer 4: (a) normal faces, (b) inverted faces, (c) feature faces, and (d) scrambled faces.

These tests supported the predicted orderings, including the lack of a difference between $S_{bc}(t)$ and $S_{cb}(t)$, with the following exceptions: for Observer 1, $S_{bc}(t) > S_{cb}(t)$ for the inverted faces; for Observer 3, $S_{bc}(t) > S_{cb}(t)$ for for the feature faces; and for Observer 4, $S_{bc}(t) > S_{cb}(t)$ for the feature and scrambled faces. Note that none of these violations compromise the interpretation of the survivor function interaction contrasts.

Figures 7.10 through 7.13 reveal that, for all observers and all stimulus types, the survivor function interaction contrasts were overwhelmingly positive. However, there was also a consistent pattern of a small region of negativity for the shortest RTs. Taken along with the results from the analysis of the mean interaction contrasts, these results place rather strong constraints on the possible inferences regarding process architectures (see Fig. 7.1). The combination of consistently positive mean interaction contrasts with positive survivor function interaction contrasts allows us, first, to rule out any form of serial processing. Although the minor negative deviations in the survivor function interaction contrasts might have suggested serial exhaustive processing, such a conclusion would require that the mean interaction contrasts be zero, which was not observed for any of the participants for any of the stimulus types. Second, we can confidently rule out any form of exhaustive processing, be it serial or parallel. For instance, to support exhaustive parallel processing would have required that the mean interaction contrasts be less than zero, something that was not observed for any of the participants for any of the stimuli. Instead, the positive mean interaction contrast, together with the small but consistent negative blips early in the $S(t)$ contrasts (IC_{SF}), followed by massive positivity, points toward parallel channels that feed into a coactive final decision path (i.e., a coactive architecture).

Capacity Measures. Our primary tool in examining capacity effects in the data is the capacity coefficient, $C(t)$ (Equation 3). As we noted earlier, the baseline (comparison) value of $C(t)$ is 1, derived for a self-terminating parallel model and indicating unlimited capacity (see Townsend & Nozawa, 1995, for a complete technical discussion). However, we also used a set of complementary measures that provide additional checks on the inferences derived from $C(t)$ and allow us to examine capacity effects as a function of stimulus type.

The complementary measures on capacity are based on two inequalities, one well known and the other less so, that have been used in work exam-

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$F(t) = 1 - S(t)$, rather than the empirical survivor function.

ining the effects of target redundancy. The first of these has been called *Miller's inequality* or the *race model inequality*. This inequality was introduced by Miller (1982), and relies on a fundamental property of probability distributions to frame a test for a class of horse-race (i.e., parallel self-terminating) models. Letting $S_{cc}(t)$ be the survivor function for RTs when both the eyes and mouth are present and clear, $S_{c\emptyset}(t)$ be the survivor function when the eyes alone are present and clear, and $S_{\emptyset c}(t)$ be the survivor function when the mouth alone is present and clear, then the race model inequality[16] can be stated as

$$S_{cc}(t) \geq S_{c\emptyset}(t) + S_{\emptyset c}(t) - 1 \qquad (5)$$

Violation of this relation is generally taken as evidence supporting the rejection of race models. As discussed by Townsend and Nozawa (1995), this inequality is implicitly based on the assumption that, at best, parallel self-terminating (i.e., race) models will be of unlimited capacity (see also Ashby & Townsend, 1986; Luce, 1986). Consequently, violation of this inequality can be taken as evidence supporting extreme supercapacity processing.

The second measure pertinent to capacity plays a role similar to that of Miller's inequality, except that it addresses the possibility of extreme limitations in capacity. This inequality has been referred to as *Grice's inequality*, as its first use appears to be in work by Grice and colleagues (Grice, Canham, & Gwynne, 1984). Essentially it establishes an upper bound for an inference of moderately limited capacity:

$$\min[S_{c\emptyset}(t), S_{\emptyset c}(t)] \geq S_{cc}(t) \qquad (6)$$

Violation of this inequality can be taken as evidence for extreme limitations in capacity. For an in-depth theoretical treatment of these inequalities, see Colonius (1990).

Finally, and as noted earlier, we took advantage of the integrated hazard function $H(t)$ as another measure of capacity (see also Townsend & Ashby, 1978; Wenger & Townsend, 2000). Note that $C(t)$, along with the Miller and Grice inequalities, looks at capacity in terms of the relation between single- and double-target conditions. As one of our central interests in this

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[16]It is more common to present the race model inequality in terms of the cumulative distribution function $F(t)$, which is related to the survivor function via $S(t) = 1 - F(t)$, and is also known as Boole's inequality. We choose to present this and Grice's inequality in terms of the survivor function to maintain consistency with our preceding focus on contrasts for $S(t)$.

work was to examine the manner in which stimulus organization might affect processing, we wanted to examine capacity independent of the effects of target redundancy. As such, we compared $H(t)$ across stimulus types to give us an indication of the degree to which stimulus organization might be affecting processing efficiency, in a relative sense. Note that none of these comparisons allow inferences regarding absolute system capacity (i.e., they cannot support inferences regarding whether the system is limited, unlimited, or supercapacity). Instead, these comparisons indicate whether preserving or violating the stimulus organization might increase or decrease the relative processing efficiency of the system.

Figure 7.14 presents the values of $C(t)$ for each of the four stimulus types for each of the four observers. Possibly the most striking aspect of these data is that, for all of the observers and all of the stimulus types, there were only limited excursions of $C(t)$ above 1, the reference value for the inference of unlimited capacity. Essentially, across the range of the RT distributions, these data suggest mild to moderate limitations in processing capacity. If the underlying architecture is coactive, as suggested by the survivor function interaction contrast results, then the deleterious effects of two, rather than one, target (vis-à-vis increasing processing load) would have to be even greater than if the architecture were simply parallel.

A second striking aspect of these data are that, for all observers, the highest values of $C(t)$ were obtained for a stimulus type other than the upright, normal faces. For Observer 1, this was the inverted faces; for Observer 2, it was the inverted faces (for the earliest times) and feature faces (for the latest times); for Observer 3, it was the inverted faces and the scrambled faces (the latter for the latest times); and for Observer 4, it was the scrambled and feature faces. Although it was the case that the specific stimulus type(s) that produced this advantage varied across observers, it was also the case that at least one nongestalt stimulus type exceeded the gestalt faces for $C(t)$ for all observers. It also was the case that the values of $C(t)$ for the normal (gestalt) faces were, for all observers, higher than those for at least one of the other nongestalt stimuli. For Observer 1, it was the feature faces; for Observer 2, it was the feature faces (for the earliest times) and the inverted faces (for the latest times); for Observer 3 it was the feature faces; and for Observer 4, it was the feature and inverted faces. At this level, then, it appears that the gestalt characteristics of the facial stimulus can both help and hurt processing. This pattern of gains and losses is consistent with the differences in the means and with observations regarding both the beneficial and detrimental effects of facial organization that exist in the literature (e.g., Kuehn, &

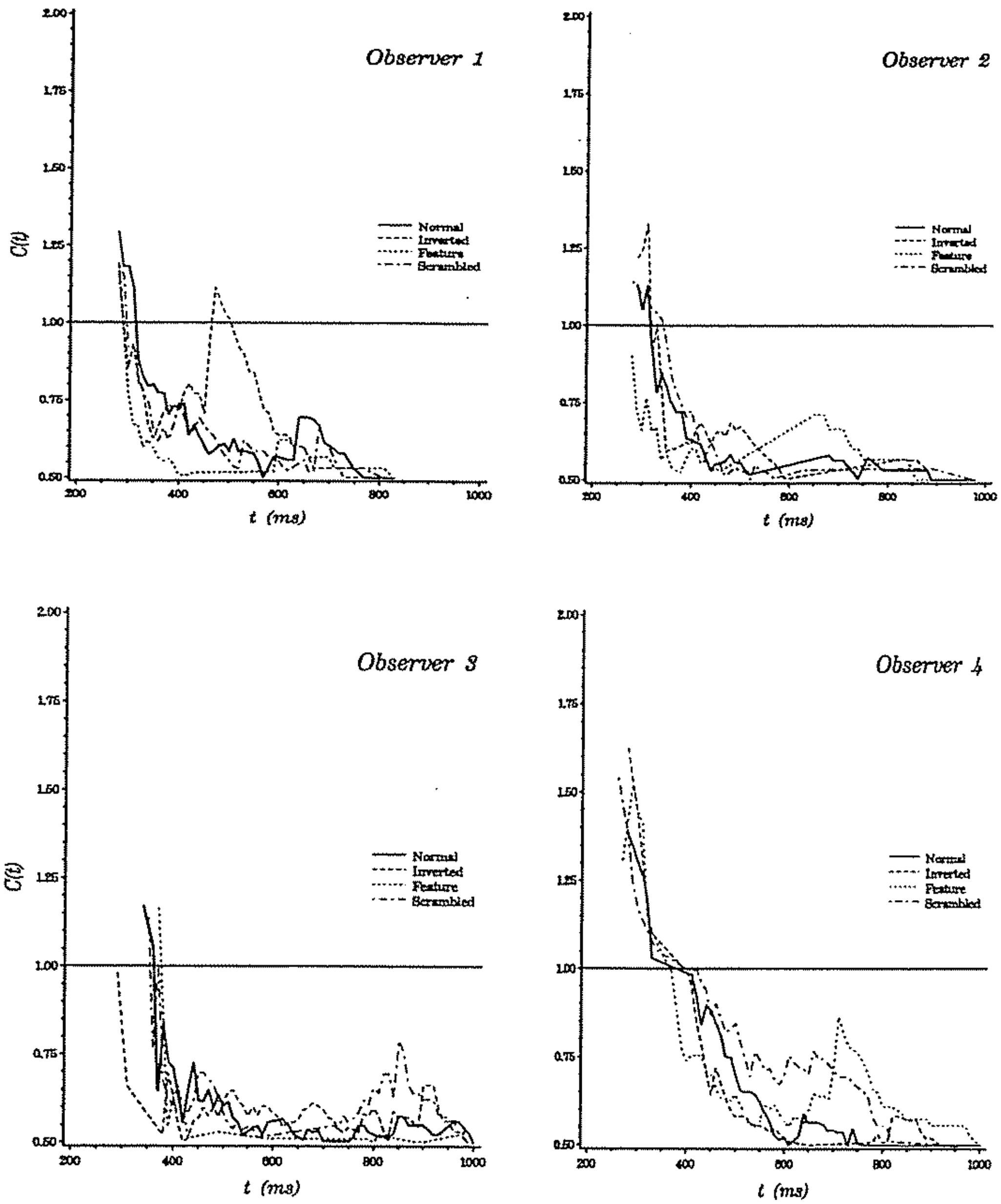

FIG. 7.14. Capacity coefficients, $C(t)$, for each of the four stimulus types for each of the four observers. The reference line at $C(t) = 1$ gives the reference value for the inference of unlimited capacity.

Jolicoeur, 1994; Suzuki & Cavanagh, 1995) and in our own ongoing investigations of the effects of stimulus configurality (e.g., Townsend & Wenger, 1996).

With the results for $C(t)$ suggesting mild to moderate capacity limitations, with almost no evidence for supercapacity processing, the Miller and Grice inequalities can be examined as a way of providing converging data. Should the Miller inequality be violated—an outcome indicative of extreme supercapacity processing—then we would be required to temper our conclusions with respect to capacity limitations and possibly bolster the evidence for coactivation. Should the Grice inequality be violated—an outcome indicative of extreme limitations in capacity—then our conclusions for mild to moderate capacity limitations would have to be altered and the evidence supporting coactivation would be compromised even further.

Figures 7.15 and 7.16 present the values of the Miller and Grice inequalities (respectively) for each of the stimulus types for each of the four observers. As can be seen in the figures, there were very few points in the RT distributions suggesting violations of either inequality. The majority of the violations were observed for the Grice inequality in the data of Observer 3, suggesting extreme capacity limitations for this observer (across all the stimulus types). There were few violations of the Miller inequality, with these violations limited primarily to the data of Observer 4. This suggests that the inferences for mild to moderate capacity limitations, across stimulus types and observers, based on $C(t)$, are sound. In any case, one clear outcome is that the preservation of facial form can both help and hinder processing in terms of processing capacity. To check this possibility further, we examined the integrated hazard functions $H(t)$ for each of the stimulus types for each observer. Figure 7.17 presents these data, which provide an index of capacity (see also Townsend & Ashby, 1978; Wenger & Townsend, 2000) for the double-target trials of each of the four stimulus types for each of the four observers.

The inferences to be drawn from these data are quite consistent with those drawn from the examination of $C(t)$. Specifically, it appears that, for all observers, preservation of the facial gestalt served to both help and hurt performance with the double-target stimuli. That is, there was at least one stimulus type that allowed for higher processing capacity (i.e., total amount of processing accomplished during the duration of the trial) than was observed for the normal (gestalt) faces. For Observer 1, it was the inverted faces for the intermediate times; for Observers 2 and 3, it was the inverted and feature faces for the intermediate times; and for Observer 4, it was the inverted faces. In addition, it was also true that there were one or two other

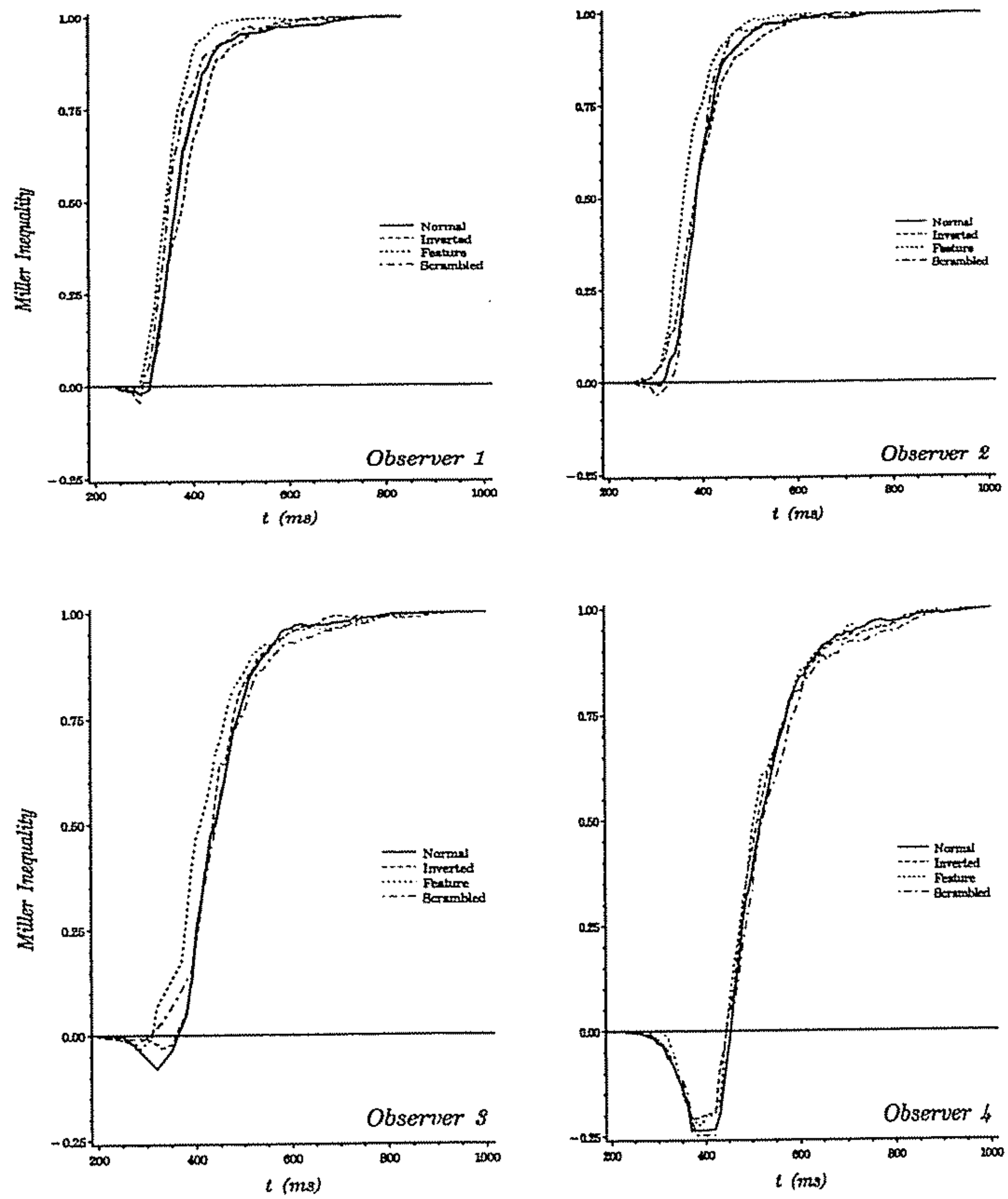

FIG. 7.15. The values of Miller's inequality, for each of the four stimulus types for each of the four observers. Violations of the inequality (values of the function less than 0) suggest extreme supercapacity processing.

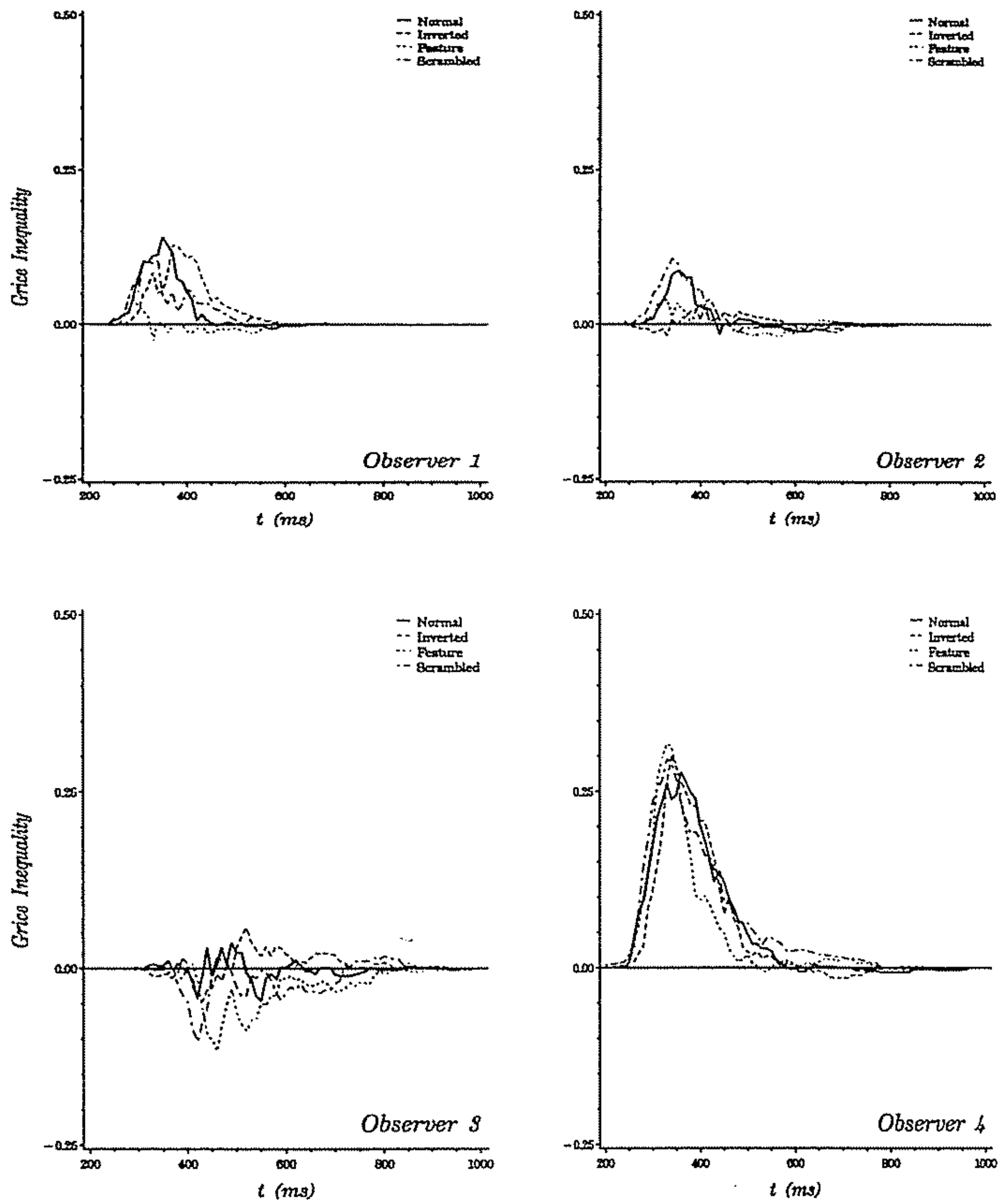

FIG. 7.16. The values of Grice's inequality, for each of the four stimulus types for each of the four observers. Violations of the inequality (values of the function less than 0) suggest extremely limited capacity processing.

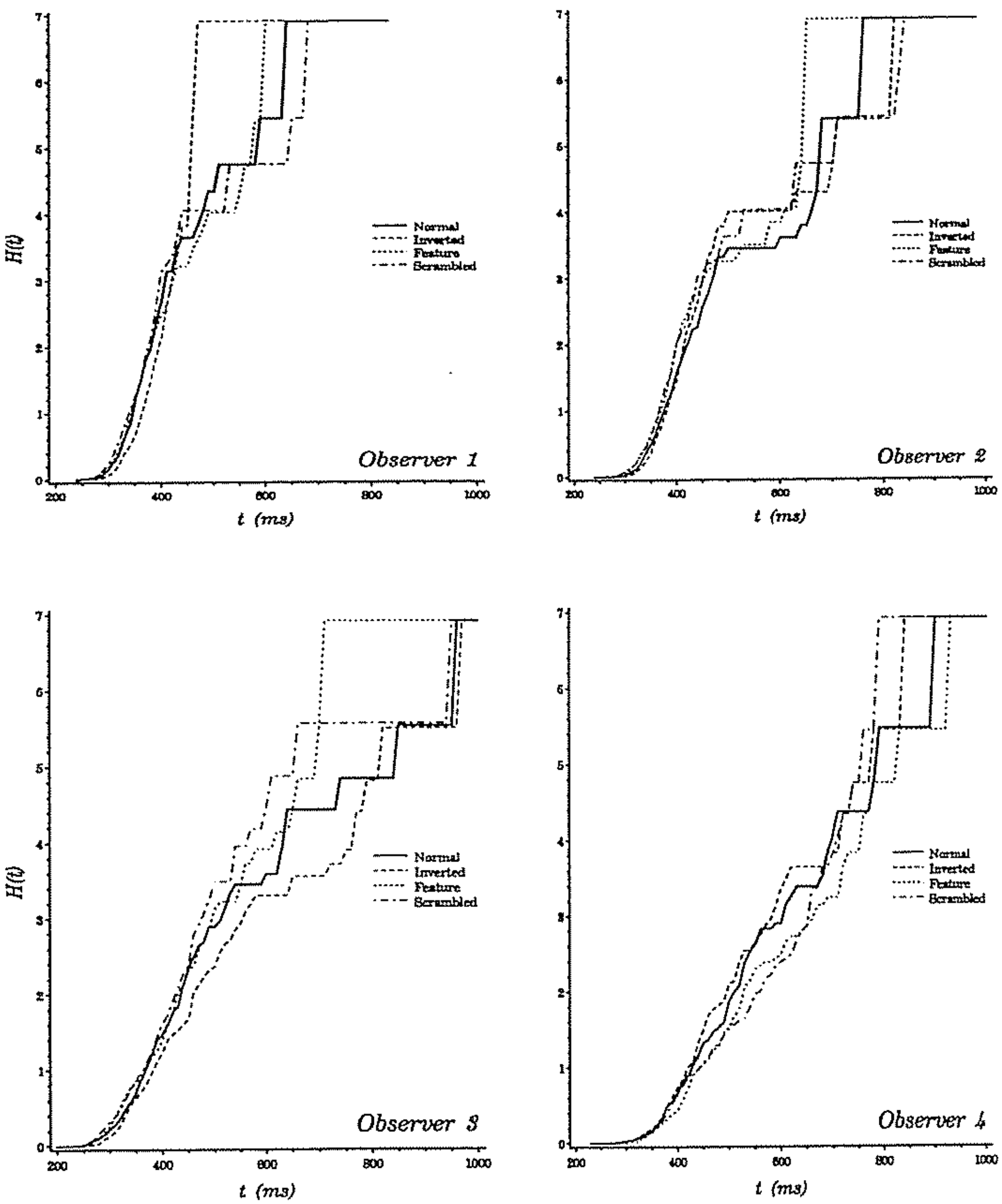

FIG. 7.17. The values of the integrated hazard function $H(t)$ for each of the four stimulus types for each of the four observers.

stimulus types that, relative to the gestalt face, produced lower levels of processing capacity. For Observer 1, it was the feature faces for the early times and the scrambled faces for the later times; for Observer 2, it was the inverted and scrambled faces for the later times; for Observer 3 it was the inverted faces; and for Observer 4, it was the inverted and feature faces. Although there are a number of plausible hypotheses for why this might be the case (and we discuss a small set of these in the Discussion), we need to emphasize that the measures as we have used them here do not speak to the source of the capacity effect. However, it is also worth emphasizing that the present methodology permits the capacity and various types of stimulus and task influences to be measured continuously across time for the first time.

DISCUSSION

As we noted in the introduction, hypotheses regarding the fundamental characteristics of the human information processor—its architecture, stopping rule, and capacity—that operate in the perception of faces have long been the subject of intense investigation and debate, albeit rarely, if ever, addressed simultaneously. Yet much of this work has proceeded in the absence of strong, theoretically motivated definitions and experimental tools, ones that can support strong inferences regarding these fundamental aspects of cognition. We have presented an initial investigation of these questions using a set of theoretical and empirical tools that are relatively new (see Nozawa et al., 1997; Townsend, 1990a; Townsend & Nozawa, 1995).

We found it surprising and fascinating that the qualitative form of the data was so consistent across observers and stimulus type. First, the mean interaction contrasts all pointed to parallel channels, although they alone cannot arbitrate between ordinary race versus coactive processing. Next, the survivor interaction contrasts all strongly supported parallel channels, with the consistent, small negative departures arguing for coactivation as opposed to simple race processing. Interestingly however, the capacity analyses were totally compatible with moderate to severe capacity limitations.

Here, we must be a bit circumspect because mild capacity limitations can be artifactually suggested by the natural contributions to RT of processes before or after (i.e., outside) the featural processing mechanisms (generally known as the residual time components; e.g., Townsend & Nozawa, 1995). Nevertheless, it was demonstrated in an important theoretical proposition by Ulrich and Giray (1986) that the presence of this time component cannot make violation of Miller's race inequality disappear. Hence, we can be certain that at the very least, coactivation based on channels that do not change with load, is firmly ruled out. Therefore, it seems that capacity must have been quite limited, especially if our conclusion with regard to coactivation is sound, as we believe it is (see the subsection on coactivation earlier in the chapter).

Despite the uniformity of the results, we did find substantial differences in capacity measures across stimulus types. In fact, our data suggest, contrary to what might be expected on the basis of intuition, that preservation of the facial gestalt can both increase and reduce processing capacity, relative to stimuli that have been widely documented to disrupt the facial gestalt. For example, inverting the face, a manipulation that has received a great deal of attention due to its ability to reduce the gestalt influences of the face, in some cases actually served to increase processing capacity above that observed with the normal upright faces. In contrast, our other disruptions of the facial gestalt resulted in reductions in the level of processing capacity from that observed with the normal faces. All of these results were obtained in the context of a consistent finding of mild to moderate capacity limitations in processing for all stimulus types and all observers.

Inferences Regarding Facial Organization of Features

What should be our interpretation of these consistent and detailed findings regarding facial feature perception? Basically, what we have is strong and consistent evidence in favor of moderate to extreme limited capacity parallel processing, perhaps with coactivation, but with a self-terminating race in the event that separate decisions are made on the two redundant target channels. Overall, the organization contained in inverted faces seemed to be most facilitative of fast processing without being so disarrayed that processing was slowed, as in the scattered-feature displays. However, feature search in true faces exacted a clear cost in processing efficiency. The responsible architecture and other important aspects of processing did not apparently change; only the efficiency with which feature search was carried out was harmed.

Perhaps inverted faces granted a coherence to feature search without imposing the human tendency to really pay attention to the face itself. All kinds of things become interesting to people about properly oriented faces: the sex, attractiveness, emotion, physiognomy, idiosyncrasies, and so on. Many of those might drain capacity instead of improving it.

Nevertheless, it is somewhat disturbing that even the scattered-feature stimuli showed evidence for coactivation. One is hard put to imagine complete pooling of the channel information, say into a grandmother cell, or complex of cells relating to that face. The hypothesis of exhaustive processing was also thoroughly defeated at least within models obeying the assumption of selective influence. Of course, in a sense coactivation completely bypasses the question, or alternatively, gets exhaustive processing by fiat.

One theoretical possibility that deserves further study and empirical probing is that although the architecture may not be actually coactive (i.e., channels might have to eventuate in their own decisions), there could be channel dependencies that to some extent, mimic coactivation. Indeed, we have demonstrated that when we produce positive dependencies among our parallel dynamic systems channels, the negative blip associated at present with coactivation can appear (Townsend & Wenger, 1997, 1998). Furthermore, initial theoretical results by Colonius and Townsend (1997) show that coactivation is a rather trivial, if extreme, case of positively dependent parallel models.

Nevertheless, our initial computations with positively dependent parallel systems indicate that, just as with coactivation, they tend toward supercapacity (i.e., in the measure $C(t) > 1$), unless efficiency on the individual channels is very limited; that is, it drops precipitously in going from one to two targets. What is not known at present is the precise relation between capacity effects in, say $C(t)$ and the two inequalities, such matters as the extent of the negative blip in the $S(t)$ contrast, and channel dependencies. In the best case scenario, some hard work might indicate that certain orderly relations can be found that are not dependent on particular distributions or parameterizations; that is, they are generic with regard to classes of models and magnitude of dependencies.

Although no striking qualitative differences appear between properly oriented faces versus randomly located features in terms of their RT process issue characteristics, we found sizable differences in terms of speed of processing. This study is the first of a planned hierarchy of experiments, wherein various aspects of the stimuli and the demand characteristics of the task become increasingly oriented toward forcing the observers to perceive the faces as integral units (e.g., a particular face is equivalent to being the individual with a particular name). Will the pattern found in this study persist to higher levels of "gestalthood"?

On the one hand, this task involves perception of components of the face, namely the mouth and eye features. On the other hand, the faces were constructed from realistic photographs, not just schematic or identikit types of stimuli (not to denigrate these stimuli, which are useful for many purposes). In addition, it is also sensible to be aware of the circularity sometimes applied to situations like this one: When a study finds something quite singular about face stimuli, then that study is taken as "really investigating face cognition." However, when the face results are similar to nonface findings, then there can always be found a reason that the stimuli, the task, the instructions, or something about the experiments were not really facelike. It is also pertinent to recall that the original and influential results by Wheeler (1970) and Reicher (1969) on the word superiority effect involved the perception of letters (i.e., read components). One simply does not know what will happen before the study, but it is questionable scientific reasoning to categorically define the characteristics of the experiment after the fact by the outcome. Nevertheless, it could turn out that task requirements that are more related to use of the face as a whole, such as identification, may find that complete natural faces are superior even to inverted faces, as has been suggested by other investigators. Such experiments are now in progress. However it turns out, the present details of feature search characteristics in several types of face-related stimuli will hopefully serve as a helpful stepping stone in beginning to limn the information processing nature of face perception.

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