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Central Sources of Visual Masking: Indexing Structures Supporting Seeing at a Single, Brief Glance

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Summary. When two briefly exposed, spatially overlapping visual fields are presented dichoptically, the identifiability of the first field is a J-shaped function of the interval separating their onsets. Three distinct sources of central masking are inferred from the selective influence of variables at different onset asynchronies. In *integration through common synthesis*, two fields presented at or near simultaneous onset yield one iconic representation. The distinctiveness of this source is inferred from the selective influence of eye dominance at and near simultaneous onset. At longer onset asynchronies, the selective influence of variables such as mask contrast and degree of contour overlap imply a second source of masking. This source was identified with the inhibition of sustained channels by transient channels reported elsewhere. *Interchannel inhibition* is proposed to affect the fidelity of the iconic representation, but here the imprecision is due to loss of form-relevant information on the first field. At yet longer onset asynchronies, where the fields are phenomenally separate, a third set of variables (e.g., words vs. nonwords and left vs. right visual fields) show their influence. These effects are taken as evidence of a *replacement principle*: the iconic representation of the second field directs attention from that of the first field. Here, first-field identifiability is constrained by time rather than by impoverished data.

In a final series of experiments, central three-field interactions are demonstrated. A field, inserted into the temporal gap between two fields, is perceptually impaired even though it is separated from the first and third fields by intervals at which, individually, neither field is an effective mask. This second-field depression is accompanied by a first-field enhancement. The three sources of central masking are hard pressed to account for the three-field effects.

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Introduction

The theoretical orientation of the present work is to analyze perceptual functions in terms of a succession of changes within the human observer (see Broadbent, 1971), an orientation that seeks to decompose perception into states or stages ordered in time, a chronometric analysis, as it were, of the successive transformations of the neural array (Turvey, 1977). There are a variety of tools to perform such an analysis, of which reaction time and masking are perhaps the most popular. Masking is the tool used here, and one is reminded that the term refers to the phenomenon of perceptual interference that results when temporally discrete, briefly exposed, and unrelated visual fields are presented in rapid succession to a stationary observer. In the limiting case of *two* temporally contiguous fields, 'forward masking' labels the case in which the lagging member of the pair is perceptually impaired by the leading member, and 'backward masking' labels the converse situation in which the leading member is impaired by the lagging member.

The contrast between forward and backward masking will figure significantly in the following experiments. However, we should recognize two further contrasts before proceeding. One of these contrasts is the distinction between monoptic and dichoptic masking. In the case of monoptic masking, the two successive visual fields are presented to the same eye; in the case of dichoptic masking, one member of the pair is presented to the right eye and the other is presented to the left eye. One ought to expect that *within certain limits* monoptic masking and dichoptic masking differ, for in the monoptic case the perceptual interference could arise at any number of neuroanatomical locations from retina to cortex, whereas in the dichoptic situation the interference has to be – in the case of humans – primarily cortical in origin.

The second contrast to be recognized is that between two functions, or rules,[1] that determine masking. The interval between the offset of the first field and the onset of the second is referred to as the interfield interval or, more conventionally, as the interstimulus interval (ISI), and the interval between the onsets of the two fields as the field onset asynchrony – or, again more conventionally – as the stimulus onset asynchrony (SOA). There is one rule that relates the *energy* of either the leading or lagging field to the ISI. This rule says that the ISI needed to produce a criterion masking effect depends on the energy of the field to be reported (target) so that the product of the two is a constant – precisely, target energy x ISI = k (Kinsbourne and Warrington, 1962a, 1962b; Turvey, 1973). This rule is described as the multiplicative rule (Turvey, 1973), but it is more usefully understood as an instance of an exponential or power function of the kind $y = kx^b$, where in this instance k is the constant and b = -1.

[1]These rules probably hold for only one temporal concatenate, *the case where one field is presented after the other has ended.* Admittedly, at very brief SOAs the two fields in this particular case would overlap, but the overall masking function would be essentially that of an interaction between two temporally nonoverlapping visual fields. There are a number of other two-field temporal concatenates (see Turvey, 1978): for example, where the target field starts after the mask field and ends before it, and where the target field starts before the mask field and ends after the mask field has started but before the mask field ends. Some of these other concatenates produce very curious results (see Standing and Dodwell, 1972; Turvey, Michaels, and Kewley-Port, 1974). As a cautionary measure, therefore, we suggest that the rules in question, derived as they were from one particular two-field temporal concatenate, should not be generalized to the others.

Insofar as the exponent may depart from -1 (e.g., Walsh, Till, and Williams, 1978; Wasserman, Lo, and Easland, 1976), it is, perhaps, more apt to describe the rule as a power rule (cf. Turvey, 1978). It is important that this rule is evident only in a rather special condition, namely, that in which the field impeding identification (mask field) must be of equivalent or greater energy than the target field in order for masking of the target to occur (see Kinsbourne and Warrington, 1962a, 1962b; Turvey, 1973).

The other rule relates the *duration* of the leading field to the ISI. For a criterion masking effect, the required ISI depends on the duration of the leading target field, so that the *addition* of the two quantities is a constant – precisely, target duration + ISI = k. More usefully, we may say that this additive rule identifies SOA as the significant variable rather than field duration, field energy, or interfield interval (Sperling, 1971; Turvey, 1973); the manifestation of this rule is not dependent on any special energy relation between the target and mask fields.

There has been a tendency to collect together and relate the data on forward and backward masking under the monoptic-dichoptic distinction (Breitmeyer and Ganz, 1976; Kahneman, 1968; Turvey, 1973). On closer examination, however, this way of classifying the data proves less than optimal, if not confusing (Turvey, 1978). A more judicious and useful classification is in terms of the two rules, in which we summarize the forward and backward masking data as follows: in conditions where the power rule prevails, forward masking is more pronounced than backward masking, both monoptically and dichoptically; in conditions where the additive rule prevails, backward masking is more pronounced than forward masking, both monoptically and dichoptically (Turvey, 1978).

Of interest in this paper is dichoptic masking in the domain of the additive rule. We take this conjunction – of dichoptic and additive – as insurance that the masking under examination is essentially of central origin (see Turvey, 1973). We hope to be able to demonstrate that a rigorous analysis of such masking is informative about the central structures supporting perception at a single brief glance[2].

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[2]In the half-dozen years that elapsed between the running of these experiments and their publication, we have come to the belief that the phenomena reported here are best thought of as indices of the central support for seeing rather than the act of seeing. The distinction, recently made by one of us (Turvey, 1977), is based on the apparent discrepancy between the continuous optical flow at the eyes that characterizes natural stimulation and the rapidly successive, discrete, and uncorrelated optical samples that are characteristic of masking research and the technology of iconic memory in general. On the assumption that visual systems evolved to deal with the former, tachistoscopic seeing becomes a situation in which the observer tries to adapt a perceptual system 'designed' for the detection of invariant and variant structure in the dynamic flux of light at the eyes (Gibson, 1966; Johansson, 1974; Shaw and McIntyre, 1974) to a relatively contrived situation which not only 'freezes' the optical flow but permits the observer no more than a momentary glimpse. It is our impression, therefore, that the data reported here – while motivated by an information-processing model and described in stage-like processing terms – are probably not revealing of perceptual processes per se but are most usefully understood as indices of the structural support for perception.

A Preliminary Account of Visual Information Processing

The experiments that follow were motivated by an account of visual information processing derived, in part, from an earlier series of experiments (Turvey, 1973). That account is presented here, in abbreviated form, for it will serve to organize the experiments and the arguments that follow.

The structured light to the eye is said to be analyzed by a set of operationally parallel and independent peripheral nets. Each net is sensitive to a different kind of arrangement in the structured light. These different arrangements could be viewed as corresponding to features [a point of view adopted in our previous work (Turvey, 1973)], or as spatial frequencies. At all events, the parallel and independent nets are assumed to respond to their preferred arrangements at different rates. If the outputs of these nets are registered in a set of central addresses, then we can suppose, on the preceding assumption, that this registration occurs across these addresses asynchronously. This latter property is a particularly significant feature of the model. Consider a central process that operates upon these stored elements: Does it wait until all outputs from all peripheral nets are registered, or does it proceed to examine each address in turn, beginning as soon as the first entry from the fastest operating net becomes available? Experimental evidence favors the latter alternative (Turvey, 1973).

We argue, therefore, that the central process that is directly contingent upon the outputs of the peripheral nets operates concurrently with the activity of these nets. For these reasons, the peripheral-central relation is referred to as 'concurrent and contingent' (Turvey, 1973).[3] This particular central process is usefully conceived of as an operation that constructs or synthesizes a short-lived 'literal' representation of the structured light at the eyes from the outputs of the peripheral nets. The process of synthesis is assumed to occur over a definite and relatively invariant period of time, the synthesizing period, with the output of slower nets injected into the synthesis at progressively later moments.

The 'literal' representation – or icon[4] (Neisser, 1967) – interfaces the central process of synthesis with the central process of identification. Synthesis relates closely to the information provided by the peripheral nets, whereas identification relates closely to the representation provided by the synthesis; therefore, a crude distinction between two central processes has been drawn. As a backdrop for our experiments this

[3]The 'concurrent and contingent' principle can be given a more general reading: There is a dependency of coarser-grained processing on finer-grained processing that is consonant with a principle by which processing at the coarser grain does not await completion of processing at the finer grain. While we have given expression to this principle in a limited domain – the relation between peripheral and central nets underlying masking – others have underscored its operation more generally, for example, Eriksen and Schultz (1979), McClelland (1979), Norman and Bobrow (1975).

[4]We interpret the experiments of Sakitt (1976), Sakitt and Long (1979), and Davidson, Fox, and Dick (1973) to mean that the *source* of iconic persistence is retinally located (see Turvey, 1977). It is this retinal persistence that supports one's ability to see extremely brief tachistoscopic exposures. The literal representation of which we speak, however, cannot be located retinally since the distinguishing of figural properties in the retinal arrangement must be supported necessarily by mechanisms beyond the retina. Therefore, we take activity in the retinal photoreceptors as the neural support for the persistence of the iconic experience, and activity at more central neuroanatomical loci as the neural support for the figural quality of the iconic experience.

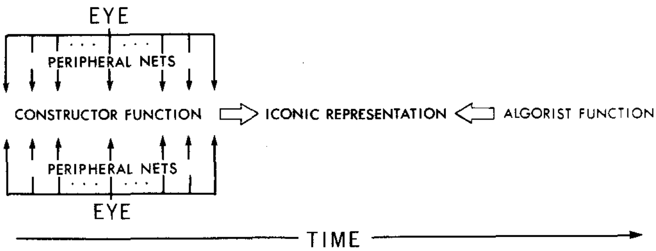

Fig. 1. A schematic of the succession of stages in the transforming neural array subsequent to a brief exposure

distinction will prove valuable; at this juncture we need to add only that the two processes, or stages, are taken to be largely separate and independent of each other.

In the preceding, we have outlined, in a rough and approximate way, a theory of what occurs in the first few hundred milliseconds after tachistoscopic stimulation. A brief summary of our view follows (see Fig. 1). Optical properties are detected in parallel and asynchronously by peripheral networks. From these properties a holistic or iconic representation of the brief visual display is synthesized by a process that operates upon, and is simultaneous with, the peripheral outflow. The iconic representation so formed is then subjected to identification algorithms: the observer comes to know what (kind of) visual object has occurred. There are, therefore, two hypothetical central operations that achieve, successively, a holistic representation and the identification of the visual object so represented. Picturesquely speaking, in terms of homunculi, the first operator may be likened to a constructor and the second to an algorist,[5] that is, one who knows and calculates algorithms.

Four Sources of Masking

We can now provide a sketch of where two discrete visual occurrences can interact in our processing model and thereby yield impairment in identification. We propose that there are four distinct types of interaction that can manifest themselves in the shape of a visual masking curve. Each will be considered in turn.

To begin, it is recognized that there are two sets of peripheral nets, one for each eye. If both of two visual fields must use the same nets by virtue of their monoptic (or binocular) presentation, then within a certain range of temporal separations the two fields will mix in these peripheral nets. We call this first interaction *integration through within-net time-sharing*: it represents competition, on the part of the two visual fields for common peripheral visual machinery. The variable determining which field will dominate is energy; the more energetic visual field will be favored in the intra-net integration (Turvey, 1973).

If the two visual fields are delivered dichoptically, on the other hand, there would be two independently detected sets of properties: one set would describe the target (the field to be identified) and one set would describe the mask (the field impeding

[5]This term is borrowed, with all due respect, from Shaw and McIntyre (1974). They have sought to lay the ground work for a rigorous definition of the knowing-agent or algorist, a concept that figures significantly, if implicitly, in cognitive theories. Our use of the term 'algorist' is merely for convenience.

identification). *Their* interaction must occur at a point in the nervous system at or beyond binocular interaction. We conceive of three such central interactions, each being maximally probable at some range of target to mask onset times.

When an exceptionally brief interval separates a target from a mask presented to the opposite eye, the two sets of properties will overlap temporally in the central addresses over which synthesis occurs. This overlap of properties represents the second type of interaction in our masking model, *integration through common synthesis*. In this circumstance, the mechanism that constructs iconic representations is faced (to a greater or lesser degree depending upon the interval) with properties of both target and mask and, in consequence, constructs a representation that amalgamates properties of both. Given that this composite is the basis for the subsequent algoristic phase, the limitation on the algorist under conditions of very brief target to mask onset asynchronies is a poorly articulated specification of target information. Performance is limited by the signal-to-noise ratio.

While the two interactions outlined above are presumed to operate in both forward and backward masking arrangement, the two interactions that follow result only in the impairment of a leading event by a lagging event, that is, backward masking. In this third type of interaction, data on the first of the two fields are lost and, therefore, unavailable for inclusion in the iconic composite. We identify this third interaction with the inhibition of slower sustained spatial frequency channels carrying form information about the target by the transient channel that signals the onset of the mask as hypothesized by Breitmeyer and Ganz (1976). It is termed *interchannel inhibition*. Within the context of the processing model presented earlier, if the mask is optimally delayed, information on the finer details of the target (perhaps those needed for identification) is not available to the constructor for inclusion in the iconic representation of the target. Our algorist, then, is left with a composite of target and mask that does not include certain essential spatial frequency data on the target.

As the temporal separation between the onsets of target and mask is further increased, there arises a fourth source of masking as *the constraint on the algorist shifts from one of imprecise target specification to one of insufficient time to process the target.* At these greater onset asynchronies, target properties arrive in the central addresses well ahead of mask properties. The constructor is thus able to achieve a holistic representation of the target, uncontaminated by properties of the after-coming mask. The construction of a representation of the latter, however, follows closely on the heels of the former. For the algorist, the circumstance is that of receiving in close succession two discrete and independent representations. The rule that the algorist obeys when confronted by rapidly consecutive icons is singularly straightforward: in the application of algorithms, lagging representations take priority.

We see, in short, that the algorist's attention is turned primarily toward the later-arriving representation, and we may suppose that the identification of the earlier-arriving representation will be a monotonically increasing function of the interval elapsing between the two. For reasons indicated above, the interval of significance is most likely that between target and mask *onsets.* In sum, at greater onset asynchronies between successive visual displays, the limitation on the algorist, with respect to target identification, is one of time. The essence of this argument is like the clerk-customer metaphor provided by Kolers (1968). When a customer enters a store, the clerk will provide the customer with all of his services. If, however, a second customer enters, service to the first customer must be curtailed. The amount of undivided service the clerk provides to the first customer is proportional to the interval elapsing between the arrival of the first customer and the arrival of the second. In this metaphor the target is the first customer, the mask is the second customer, and the algorist is the clerk. Thus, we see the mask as abrogating the service of the algorist, replacing the target as the principal object of the algorithms. An important feature of this fourth source of masking, *replacement*, is that, in principle, information on the first field survives – it is only 'replaced' as the main object of algoristic attention.

This concludes our preliminary remarks. We have hypothesized that there exist two distinctively different and separable phases in the first 200 or so ms of central visual activity subsequent to a briefly exposed display. Further, we have hypothesized three central effects of a mask on a target that can occur within or between these phases and, additionally, one effect that is limited to more peripheral loci. These interactions contribute to the function relating target identifiability to the temporal separation between target and mask. Let us now proceed to examine the worth of these speculations.

A. The Dichoptic Masking Function and Stimulus Onset Asynchrony

Experiment A 1

The first experiment asks two very simple questions: First, what is the shape of the dichoptic, backward masking function for a spatially overlapping target and mask; and second, how do dichoptic and monoptic masking functions for two target-to-mask energy ratios differ where one ratio favors the target and the other the mask? Previous research has revealed that the target-to-mask energy ratio determines the shape – from monotonic to nonmonotonic – of the monoptic backward masking function (e.g., Spencer and Shuntich, 1970; Weisstein, 1971; Turvey, 1973), and that dichoptic masking is far less sensitive than monoptic/binocular masking to the energy of stimulation (Turvey, 1973). Considering these observations, we would expect the dichoptic and monoptic functions to respond differently to the energy manipulation.

However, there is a further and more significant expectation: whether the two visual displays are presented to the same eye or to separate eyes should prove immaterial at some point in the flow of information to the nervous system. Most obviously, the process of synthesis and, in turn, the process of identification are sensitive to the peripheral interactions that can occur when two optical occurrences share the same set of peripheral channels, as is possible with monoptic presentation. Beyond some onset asynchrony, between monoptically presented target and mask, peripheral interaction must be absent. Similarly, beyond some onset asynchrony value, mask properties arrive too late to affect the synthesis process and, we may conjecture that this asynchrony value will be identical for both monoptic and dichoptic presentation. We are led by this line of argument to the following conclusion: beyond some onset asynchrony value, monoptic and dichoptic masking ought to be identical, for both will reflect nothing other than the temporal limitation on the algorist.

Method. A six-channel Scientific Prototype tachistoscope (Model GB) was used for the presentation of target, mask, and background fields. The two three-channel units of the tachistoscope permitted both monoptic and dichoptic viewing. One of the units could be adjusted to conform to the observer's interocular distance and a comfortable convergence angle. For both monoptic and dichoptic masking conditions, one dark slide with a small, centrally located pinhole was placed in each unit for dichoptic fixation. The fields of the tachistoscope subtended 3.5° vertical by 6.5° horizontal at a viewing distance of 39 cm.

One hundred 35 mm slides of black consonant trigrams set in Stenso Gothic capital and arranged horizontally against transparent film were used as targets. The three letters of each slide were drawn from the set of all consonants (except b, f, p, and y) with the restriction that no letter was repeated within a slide. Each letter subtended 0.67° vertical by an average of 0.36° horizontal. The thickness of the parts of a letter was 0.13° of visual angle and each letter was separated from its neighbor by an average of 0.40°. One consonant trigram, PBF, was used as the mask. The luminances[6] of the target and mask were both set at 27.2 cd/m^2 and the fixation fields in the two units of the tachistoscope were set at 0.07 cd/m^2. All measurements were made with a SEI exposure meter. Target to mask luminance ratios of 1:2 and 2:1 were obtained by placing a Kodak neutral density filter (50% transmission) in the filter holder of the desired channel on the tachistoscope. All displays were presented for 10 ms.

Eight Yale University undergraduates were paid $ 2 for their participation as observers. Each received 40 trials at each of seven SOAs (0, 10, 25, 40, 70, 100, and 150 ms). The 40 trials consisted of 20 trials using a target-to-mask luminance ratio of 2:1 (10 monoptically and 10 dichoptically), and 20 trials using a ratio of 1:2 (10 monoptically and 10 dichoptically). The experiment was run in four blocks of trials corresponding to the Luminance ratio by Eye arrangement combinations. Within each block, SOA increased in groups of 10 trials. Two observers began Block I with one of the four conditions, two with another condition, and so on. Eye was balanced between observers.

Results and Discussion. The numbers of letters correctly identified in each condition were averaged over observers, and the resulting percentages are plotted as a function of SOA in Figure 2. For statistical analysis the observations were summed over trial and eye. An Observer × target-mask Eye Relationship × Luminance ratio × SOA analysis of variance (ANOVA) was performed on these summed data. All the main effects and interactions were significant ($P < 0.01$), with the exception of the main effect of Eye relation, $F(1,7) = 0.136$. (The denominators of these and the F-ratios for other experiments are interactions with observers; for experiments in which there are between-observer variables, the error terms are the interactions with observers within group.) These significant effects are captured by the second-order interaction: Eye Relation × SOA × Luminance ratio, $F(6,42) = 12.9, P < 0.01$. Inspection of Figure 2 reveals that at brief SOAs the luminance ratio effect is more pronounced monoptically than dichoptically, while at longer SOAs the effect of luminance ratio is not observed for either eye relation.

[6]For each experiment in the present communication, the reported luminance refers to the luminance of the area surrounding the black target letters or mask forms. This luminance was always recorded at the eyepiece of the tachistoscope.

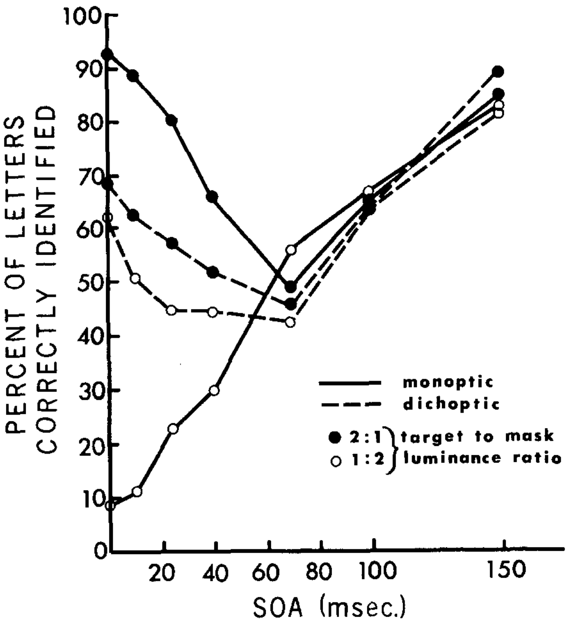

Fig. 2. Relation between target identifiability and SOA for monoptic and dichoptic masking under two target-mask luminance ratios in Experiment A1

We now proceed to the implications of these results from the perspective of the model of visual processing and the four sources of masking described earlier. This experiment is discussed in some detail since it lays the groundwork for much of the research that follows.

Consider the role of *integration through within-net time sharing.* Recall that this interaction is presumed to occur when the target and mask must share the same peripheral nets. A comparison of performance under monoptic presentation with that under dichoptic presentation permits the assessment of several properties of this intra-net effect: its magnitude, the variables of stimulation that influence it, and the range of SOAs over which it occurs.

First, it is evident that intra-net effects can be very powerful; they can structure the very character of the masking curve from monotonic to nonmonotonic (cf. Turvey, 1973, Experiment XVIII). Second, we observe that energy is the variable relevant to the determination of which of the two brief displays, target or mask, will dominate the peripheral nets. Given simultaneous presentation, for example, a target with twice the luminance of a mask, exposed for the same duration as the mask, will be identified almost perfectly, whereas the inverse energy relation will yield an unidentifiable target. Third, it can be seen that the range of onset-to-onset intervals over which peripheral mixing can occur is quite small. The point at which the monoptic and dichoptic curves merge represents the SOA at which significant impairment in target identifiability can no longer be attributed to within-net integration. At that point, presumably, influences on the shape of the masking curve are yielded to relatively central factors.

If peripheral interaction is precluded when the target and mask are delivered to opposite eyes, then the shape of the entire curve should be owing in the main, to these central influences. Consider, therefore, the dichoptic curves of Figure 2: their most notable feature is their nonmonotonicity; they are J-shaped. To the best of our knowledge, nonmonotonic masking functions with a dichoptically presented, partially overlapping pattern have not previously been reported. Indeed, it has been speculated (e.g., Breitmeyer and Ganz, 1976) that such dichoptic functions are unique to the metacontrast paradigm in which the target and masker are spatially contiguous but not overlapping.

In addition to depicting the general shape of the dichoptic function, Figure 2 suggests that distinctions based on energy are minimally relevant to central visual processes and then only over a small range of SOAs. At a point coincident with the merging of the monoptic curves, the dichoptic energy effects disappear as well as the monoptic-dichoptic contrast.

At present it is not our intention to provide a thoroughgoing analysis of why the dichoptic masking function is shaped the way it is – such is the task of the following experiments. For now, it is sufficient to make a few observations about the shape of the curve and to sketch out where in the curve the various central interactions proposed earlier are expected to exert their influence.

Over some range of target-to-mask intervals, referred to earlier as the synthesizing period, one iconic image represents properties of both visual fields. If the target and the mask are presented monoptically during this period, then the icon will embody properties of the more energetic field, since competition for the use of peripheral networks is energy-dependent. However, the shared gist of the concurrent-contingent scheme (Turvey, 1973) and the spatial-frequency channels notion (Breitmeyer and Ganz, 1976), is that as the onset asynchrony between two monoptically presented fields increases, the number of nets or channels over which time-sharing occurs, decreases. We may suppose, therefore, that the icon synthesized becomes increasingly less dominated by the more energetic field as the fields are made temporally less proximate (see Figure 2).

Dichoptic presentation circumvents, in very large part, the confounding of integration through common synthesis by integration through within-net time-sharing. With two fields presented dichoptically within the synthesizing period, it is assumed that the constructor of the icon uses parts of two independently determined data bases to synthesize an icon that represents, in consequence, a composite of the two fields. Furthermore, it is assumed that during the period of synthesis, the sustained channels providing data on the identification-relevant details of the first field are inhibited to varying degrees as a function of onset asynchrony. Indeed, the observation of decreasing target identifiability with increasing onset-to-onset time (the descent of the initial part of the dichoptic curve depicted in Figure 2), suggests that the inhibition of first-field sustained channels by second-field transients was a more potent source of masking than integration through common synthesis was.

In short, it is proposed that Figure 2 manifests three kinds of interaction between the target and mask that may be interpreted as contributing to the construction of a 'messy' but persistent icon. Under the conditions of these interactions, the problem confronting the algorist is that of identifying a string of letters whose representation is degraded.

Beyond some point on the SOA dimension, however, the degrading sources of masking become inoperative, and variables such as manner of presentation (monoptic or dichoptic) and energy relationships between the two fields become relatively immaterial. At that point, supposedly, the information in the set of central addresses is limited to target information. Thus, the constructor synthesizes a lucid iconic description of the target for algoristic attention. Under this condition the algorist's difficulty is not that the target representation is impoverished, but rather that attention is directed away from the target representation to the after-coming representation – that of the mask. Whether the algorist will have sufficient time to deal with the intact target icon will depend, we think, on variables other than those that are responsible for the difficulties with degraded icons.

There is a final issue requiring comment: the relative magnitude of monoptic and dichoptic masking. It has been argued (e.g., Dick, 1974) that monoptic masking effects must be more potent than dichoptic masking effects because monoptic presentation can yield effects over and above central interaction. Experiment A1 demonstrates that, depending on the parameters of stimulation, monoptic masking may be greater than, equal to, *or* less than dichoptic masking (cf. Turvey, 1973).

Experiment A2

It was remarked above that the conjunction of dichoptic presentation and SOA as the relevant temporal variable can be taken as insurance that the masking in question is unlikely to be of peripheral origin and most likely to be of central origin. That dichoptic masking need not follow the additive rule and may follow the power rule, was shown by Kinsbourne and Warrington (1962b). There is reason to believe, however, that in the general case, it is the additive rule that describes dichoptic masking (Turvey, 1973). It is our understanding that the power rule is dominant dichoptically only under conditions in which the target exposure is near threshold and the mask energy exceeds target energy by a considerable amount[7] – conditions that do not hold for the present series of experiments.

Nevertheless, we would like to make explicit the relevance of SOA to the entire span of the dichoptic masking function before proceeding to examine our speculations about central sources of masking. Consequently, the second experiment pits ISI, target duration, and SOA against each other to determine the best temporal predictor of dichoptic pattern masking in conditions representative of the target-mask relations of the preceding experiment and of those that follow.

Method. A Scientific Prototype three-channel tachistoscope (Model G) was modified with polarizers for dichoptic viewing. The fields of the tachistoscope subtended 7^{o} horizontal by 5^{o} vertical. A binocularly visible channel of the tachistoscope presented a constantly illuminated white point on a black field (luminance of 1.7 cd/m^2) for fixation.

Four Lake Forest College undergraduates were presented block letter trigrams to one eye, followed at various SOAs (0, 10, 20, 40, 50, 60, 80, 100, 150, 200ms) by an equal-energy mask (108 cd/m^2) to the other eye. The mask was a collection of eight nonoverlapping block letters drawn backwards at various orientations. The area covered by the mask completely overlapped the area of the target trigram.

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7 Kitzman: Personal communication

Three target durations (10, 20, and 50 ms) were used; the mask duration was constant at 50 ms. The concurrent manipulation of target duration and SOA results in changes in ISI. Thus, this design permits the evaluation of the relative contributions to masking of target duration, ISI, and SOA.

For balance, the experiment was divided in half. For two subjects, the targets were delivered to the right eye and the mask to the left in part 1, and vice versa in part 2. The other two subjects received the reverse order. In blocks of 15 trials (five trials at each target duration, randomly arranged), SOA increased in part 1 and decreased in part 2 for two subjects, while the other subjects received decreasing and then increasing series in parts 1 and 2.

Results and Discussion. The percentages of letters correctly identified for each target duration by SOA combination were computed and the averages are presented in Figure 3 as a function of these two variables. The effect of target duration (and thus, ISI) was nonsignificant, $F(2,6) = 0.240$, as was the SOA x target duration interaction, $F(18,54) = 0.494$.

The main effect of SOA was quite reliable, $F(9,27) = 48.12, P < 0.001$. In fact, if we add the variability attributable to SOA together with the variability attributable to subjects, these two factors account for 91% of the variability observed in the present experiment. These statistics simply confirm the obvious trend in Figure 3; namely, that the three curves are virtually overlapping, thereby pinpointing SOA as the variable of greatest relevance.

B. Integration Through Common Synthesis

Experiment B1

Experiments A1 and A2 provide the backdrop for an analysis of the sources of masking proposed in the introduction. To reiterate, the principal concern is with central

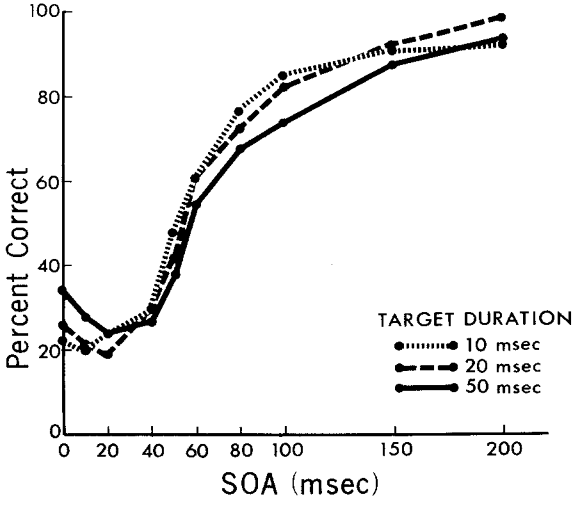

Fig. 3. Relation between target identifiability and SOA for dichoptic masking at three values of target duration in Experiment A2

masking effects. Having acknowledged a peripheral source of masking in Experiment A1 (integration through within-net time sharing), we now direct our attention exclusively to dichoptic masking functions. Knowing that SOA is the temporal parameter of greatest relevance here, we shall attempt to demonstrate that dichoptic masking arises from three distinct and dissociable central sources. Experiments B1 and B2 examine the first of these proposed central interactions: integration through common synthesis.

The phrase 'integration through common synthesis' is meant to summarize a situation in which the icon constructor builds a composite icon out of data from two independent sets of peripheral nets, one set carrying target data and one set carrying mask data. It is supposed that the data from two sets of nets can arrive in such temporal proximity that they cannot be resolved into two temporally discrete visual objects.

How might such an effect, the effect of common synthesis, be observed in the *absence* of a confounding by other sources of masking? The answer appears to lie with dichoptic *forward* masking by pattern: dichoptic presentation precludes within-net interactions and the forward paradigm (that is, where the mask precedes the target) allows for *neither* interchannel inhibition nor icon replacement.

Experiment B1 contrasts dichoptic forward masking with its backward masking counterpart. Backward masking, by our analysis, embodies all three central masking components: integration through common synthesis, interchannel inhibition and icon replacement.

Method. In the present experiment, two visual fields were presented for identification at various SOAs (0, 20, 40, 60, 70, 80, 100, 150, 200, and 250 ms). This technique permitted the conjoint measurement of impairment of the leading target by the lagging target and vice versa, that is, the measurement of both forward and backward masking effects.

The tachistoscope was the one described in Experiment A1. The two target sets were the sets described in Experiment A1 and another set of 100 constructed in an identical manner. The two sets were ordered in pairs, one from set 1 and one from set 2, such that corresponding trigrams from the two target sets were spatially overlapping but did not share a common letter.

Each target was presented for 10 ms at a luminance of 13.7 cd/m^2. (The fixation fields in the two units of the tachistoscope were at a luminance of 0.07 cd/m^2.) On any one trial, one of a target pair was dichoptically followed by its partner.

Six Yale University undergraduates were told that on each trial they would be presented with two sets of three letters. They were instructed to report as many of the six letters as they could.

Each subject received 20 trials at each onset-to-onset interval, 10 in which the leading target was delivered to the right eye and the lagging target to the left eye, and 10 in which the leading target went to the left eye and the lagging target went to the right eye. The first half of the experiment used one eye relationship, with SOAs either increasing or decreasing in blocks of 10 trials. The second half used the other eye relationship and the other block type. The various combinations were distributed among subjects.

Results and Discussion. The numbers of items reported from each target (the leading and the lagging) were averaged over trials, eye order (L-R vs. R-L), and subjects. The results are plotted in Figure 4. The backward masking function, that is, the curve for the leading target, shows a nonmonotonic masking relationship. The forward masking function, that is, the curve for the lagging target, shows increased target identifiability with increasing SOA.

A Subjects x Eye x Order (leading vs. lagging) x SOA ANOVA yielded four significant effects: SOA, $F(9,45) = 10.57, P < 0.01$; Order, $F(1,5) = 21.69, P < 0.01$; the Eye x SOA interaction, $F(9,45) = 3.71, P < 0.01$; and the SOA x Order interaction, $F(9,45) = 10.76, P < 0.01$. The origins of the main effects of SOA and Order and their interaction are evident on inspection of Figure 4 as follows. On average, target identifiability increases with increasing SOA. On average, report of the lagging target is superior to report of the leading target. The interaction is a result of differential performance on the leading and lagging targets at different SOAs.

Finally, the Eye x SOA interaction deserves mention. At simultaneous onset, an effect of eye was observed; targets presented to the right eye were identified more readily than those presented to the left eye. This superiority diminished with increasing onset-to-onset time. This effect may be a result of eye dominance; we shall return to this notion in Experiment B2.

Let us now proceed to the implications of this experiment vis-à-vis the conceptions of masking presented earlier. First, the forward situation resulted in far less masking than the backward situation (see also Smith and Schiller, 1966; Greenspoon and Eriksen, 1968; Uttal, 1975). This is consistent with the thesis that backward masking involves masking effects above and beyond that operating in the forward paradigm. We observe, as well, that the forward function demonstrates most severe masking effects at SOA = 0. This supports our contention that integration underlies the dichoptic forward masking curve, for at what point, other than SOA = 0, would we expect the resolution into two temporally discrete displays to be most difficult?

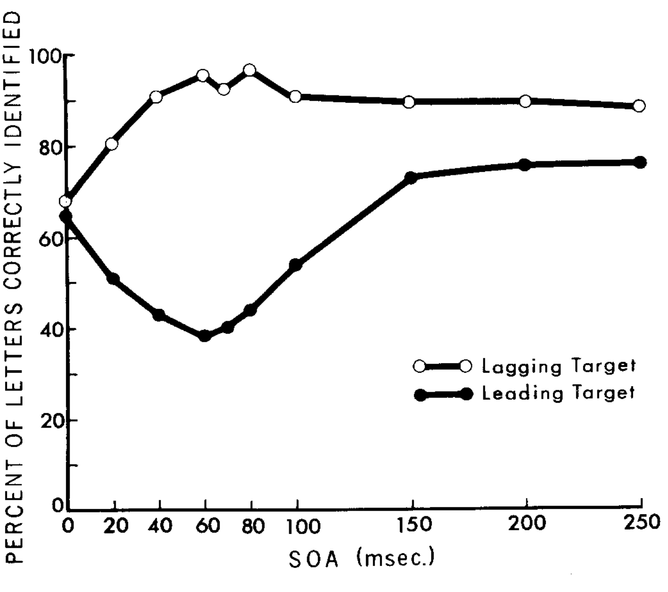

Fig. 4. Relation between letter identifiability and SOA for the leading and lagging fields presented dichoptically in Experiment B1

Forward masking effects disappear quite rapidly as SOA increases; in the current perspective, we infer that there is a relatively narrow range of intervals, over which uninhibited data sets arriving from different eyes are synthesized into a common icon. The reason that the forward (and backward) curve does not reach 100% is probably owing to limits on short-term memory, rather than to masking considerations. Recall that on each trial, subjects were asked to report six letters.

Backward masking effects, in contrast, are neither limited to such a small range of SOAs nor monotonically related to SOA. We suppose that both the protracted range of onset asynchronies and the nonmonotonicity are attributable to interference on the leading event by the lagging one, and not vice versa. To reiterate two earlier speculations: first, there are two sources of masking that should be evident in the backward but not the forward situation – namely, interchannel inhibition of sustained channels by transient channels and icon replacement; second, the J-shaped backward masking function is evidence for the greater potency of interchannel inhibition over integration through common synthesis.

Integration through common synthesis, the proposed source of dichoptic forward masking, operates in dichoptic backward masking. However, the 'pure' effects of backward integration are obscured by the additional sources of dichoptic backward masking noted above. It is of interest to ask, however, whether forward integration is equal to 'pure' backward integration (that is, backward masking uncontaminated by interchannel inhibition and icon replacement). If we could isolate a dichoptic backward masking function that is due *solely* to central integration, would this function and the forward masking function be symmetrical?

In the context of the two homunculi – the constructor and the algorist – the question is whether *the constructor* favors the leading or the lagging visual field. That is, when two visual fields succeed rapidly, will the constructor create an icon that uses as its primary data either the leader or the lagger? On the earlier assumption that the constructor simply *cannot* resolve a target and a mask that are virtually simultaneous into temporally distinct objects, we would predict that the constructed icon will be equally likely to embody aspects of the leading field and of the lagging field. The hypothesis that equal forward and backward masking arise from integration through common synthesis assumes that the constructor is dealing with two *complete* sets of data. At larger target-mask asynchronies, significant data on the leading field are suppressed by the lagging field's transient channel (Breitmeyer and Ganz, 1976) and a very different assumption is made, namely, that of *incomplete* data on the leading field.

To summarize, dichoptic backward and forward masking functions have been contrasted. Forward masking was limited to a relatively small range of SOAs and related monotonically within that range. Backward masking occurred over a much larger range of SOAs and its function was J-shaped. It was argued that forward dichoptic masking by pattern provides a pure measure of the masking effects that arise via integration through common synthesis. Such integration arises also in the backward case, but the backward masking function is confounded with other sources of masking. The issue of whether backward and forward integration were equal was raised and it was hypothesized that they should be the same. Experiment B2 examines that hypothesis.

Experiment B2

Experiment B2 asks whether integration through common synthesis is symmetrical about SOA = 0. That is, will the iconic synthesis of two visual fields, asynchronized by a few milliseconds, represent data equally from both fields?

This question should yield to two approaches. The first is that of identifying some mask that integrated with a target, but that had neither a transient signal (to inhibit target data) nor an independent iconic representation (to usurp the algorist's attention). Given such a mask, we would simply compare its relative effectiveness in the forward and backward cases; such a mask, however, was not immediately obvious to us.

A second approach to the symmetry question seeks to isolate central integration by comparing two curves that differ *only* in the integration stage. Imagine, for example, that one of two dichoptically presented visual fields dominates in integration through common synthesis, but does not dominate in the other source of visual masking. A comparison of the masking curve of the dominant visual field with that of the visual field that *is dominated*, should reveal the locus and extent of integration effects. We would then ask whether the *difference* between these two hypothesized curves is symmetric about SOA = 0.

If the constructor does favor one set of data over another (for some reason other than relative temporal position), the resulting iconic composite would be primarily a representation of the favored input. In this case, we ask over what range of SOAs is the favored input favored and is the preferential treatment equal in the forward and backward cases? One candidate for such differential treatment may have been revealed in Experiment B1, namely, eye effects. It is not unreasonable to suppose that the term 'eye dominance' describes the situation in which the constructor is partial to the input from one of the two sets of peripheral visual nets.

A closer examination of the eye effects reported in Experiment B1 provides a second motivation for examining the role of eye dominance in central integration. It was the Eye x SOA interaction that was significant. In particular, we recall that differential performance as a function of eye was evident only at brief onset-to-onset times. At longer intervals, the left and right eyes did not differ.

These speculations set the stage for several predictions about the dichoptic pattern-masking functions of a dominant versus a nondominant eye. First, among subjects showing pronounced dominance effects, performance at SOA = 0 should be better for a target presented to a dominant eye than for a target presented to a nondominant eye. Assuming that eye dominance is related to integration, we would further predict that the range of onset-to-onset times over which eye differences are observed would be limited to that of the integration curve, that is, the forward masking curve, identified in Experiment B1. Finally, if the symmetry notion is not in error, the *difference* between masking curves for the dominant and nondominant eyes should be symmetrical with respect to SOA = 0.

The present experiment sought, therefore, to describe the form of two masking curves, that of a dominant eye and that of a nondominant eye.

Method. Four Lake Forest College students who in previous experiments had shown relatively strong dominance effects, that is, differential eye performance at SOA = 0, were asked to participate. The 'backward-letters' mask, described in Experiment A2, dichoptically preceded or followed black letter trigrams. The equipment and parameters of stimulation were those used in Experiment A2, with the exception that target and mask durations were set at 10 ms. Ten trials were given to each eye at each of 12 SOAs. The experimental session was divided into two parts comprising 12 blocks (ascending or descending in SOA) of 10 trials. Two subjects received part 1 targets to the left eye and part 2 targets to the right eye. The opposite order was given to the other two subjects.

Results and Discussion. The percentages of correct responses were averaged over trials and subjects and are plotted by eye (dominant vs. nondominant) in Figure 5. An Eye x SOA x Subjects ANOVA revealed three significant effects. Letters delivered to the dominant eye were, on average, identified more accurately than those delivered to the nondominant eye, $F(1,3) = 22.01$, $P < 0.025$. SOA, as usual, accounted for a significant amount of variance, $F(11,33) = 19.13$, $P < 0.001$. Most important, however, was the observation that eye effects differ as a function of SOA, $F(11,33) = 9.10$, $P < 0.001$. In particular, *eye dominance effects are limited to brief onset-to-onset times.*

Before proceeding to the symmetry issue, let us examine these results in more detail. To begin with, there is virtually no forward masking of a target presented to the dominant eye. The backward masking is very strong and is a U-shaped function of SOA. A target presented to the nondominant eye, on the other hand, is heavily masked by a preceding event on the dominant eye. The backward curve for the nondominant eye is only slightly J-shaped, although a more pronounced decrease in performance with increasing SOA may have been obscured by the obvious floor effects. At a point in the backward functions, the eye effect is drastically reduced and it makes no difference to which eye the target is delivered.

The existence of two such different masking functions suggests that the dichoptic J-function described earlier might have been an artifact of averaging over eyes. We must recall, however, that the subjects whose results are reported in the present experiment

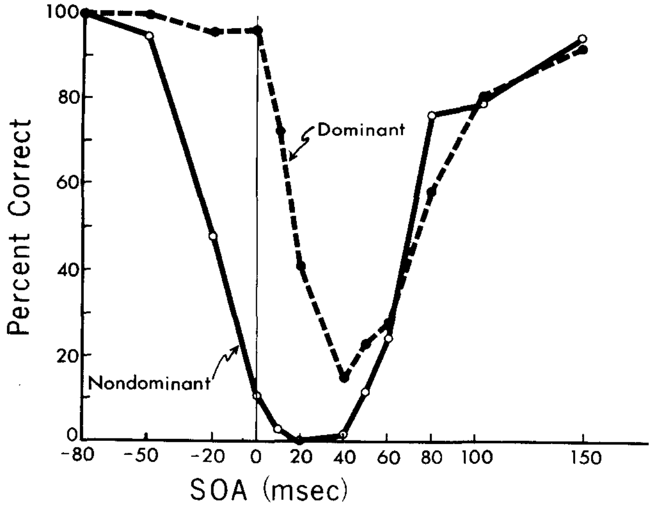

Fig. 5. Relation between target identifiability and SOA for dichoptic forward and backward masking with the target presented to either the dominant or the nondominant eye in Experiment B2

were selected for their strong dominance. It has been our experience that the average subject shows a smaller effect and that both curves, that for the dominant eye and that for the nondominant eye, are nonmonotonically related to SOA. Indeed some subjects show identical (and nonmonotonic) curves in both eyes (e.g., in Experiment A2).

One purpose of Experiment B2 was to determine whether integration through common synthesis was indifferent to the order of presentation of the two visual fields. We computed the difference between the dominant and nondominant curves (see Fig. 6) and asked whether this difference is equal in the forward and backward curves. Inspection of Figure 6 reveals that this difference is almost perfectly symmetrical about SOA = 0. It might be concluded that the privileged access to the constructor of a visual field from the dominant eye is indifferent to the order of the fields.

There may, however, be a more important conclusion to be drawn from this experiment: we must be skeptical of the idea that there is *one* curve that describes dichoptic masking by pattern. Rather (and we shall see this many times in the experiments that follow), there are many variables that can drastically alter the character of the curve as eye dominance does. And most important, the restricted range of onset asynchronies at which dominance effects emerge suggests that the mechanisms supporting masking at these intervals may be different from those supporting masking elsewhere in the curve. While other variables (e.g., figural relations between target and mask) have shown their influence in this range, they do not do so exclusively (Hellige et al., 1979).

A summary of our understanding of integration through common synthesis follows. Two sets of data, one arriving from one eye and one arriving from the other eye, can be mixed to yield one composite icon. Several variables can influence whether the recipe for this mixture favors ingredients from one data set over another. We have identified one variable to be eye dominance. Experiments B1 and B2 both suggest that this integration operates only when two visual fields are presented either simultaneously or in very rapid succession. Both the forward masking curve (Fig. 4) and the integration curve (Fig. 6) show rapid diminution with even small increments in onset asynchrony. In addition, it has been observed that within the integration interval the order of arrival of the two visual fields does not matter.

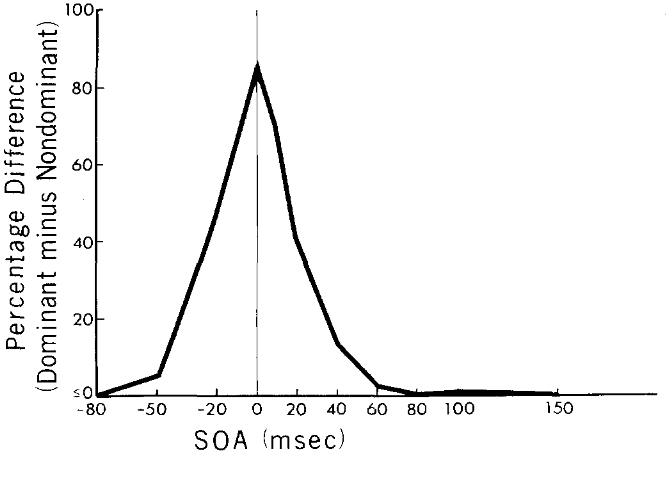

Fig. 6. The computed difference between the dominant and nondominant functions of Figure 5

As the target and mask are temporally separated, the advantage accruing to a field dominating in integration is yielded to the later-arriving field which, as Figure 5 suggests, is an effect independent of the eye of presentation. As reasoned earlier, the advantage of the later-arriving field can take two forms. First, the transient signal of the second field can inhibit the arrival of data about the earlier field and thus be more fully represented in an icon that only partially represents the earlier field. Second, at larger SOAs an iconic description of the second field will abruptly divert the algorist's attention from the icon of the first. It is interesting to note that if our interpretations of Experiment B2 are correct, then the curve depicting performance of the dominant eye in Figure 5 is due, exclusively, to these last two forms of two-field interaction. Given strong dominance, there is very little 'integration'; the visual field of the dominant eye simply prevails. Thus, the curve representing the dominant eye shows a backward masking function that, for all intents and purposes, lacks an integrative component. Following this reasoning, this curve embraces only the other two forms of central masking, interchannel inhibition, and icon replacement. Our attention is now turned to these sources of central masking.

C. Interchannel Inhibition

Experiment C1

It has been argued that the constructor synthesizes one composite iconic representation of two visual fields if those fields arrive in sufficiently close temporal proximity. Within this synthesizing period two types of central interaction are presumed to operate. In the first type of interaction (examined in Experiments B1 and B2), data from both fields are included in the synthesis independent of their order of presentation. However, as the onset-to-onset interval of the two fields is increased, a second factor, the inhibition of sustained channels by transient ones is brought to bear. In this interaction, the synthesis clearly favors the later-arriving of the two fields. Form-related spatial frequency data on the first visual field are inhibited by the transient burst from the second visual field and are, therefore, unavailable for inclusion in the composite icon. Under these circumstances, then, the first of the two visual fields is underrepresented in the iconic composite. The task of the algorist in identifying the first visual field is doubly difficult; not only is one dealing with a composite icon but the data of interest may be grossly underrepresented.

If these notions are correct, then there ought to be variables of stimulation that induce differential masking effects in this second form of central interaction. Precisely, if there is an additional central interaction in icon synthesis that influences icon fidelity at intervals longer than the period defined in Experiment B2, then varying some appropriate parameter of stimulation should effect a change in the masking curve at the points in the curve corresponding to those onset asynchronies. We think we have found such parameters, albeit serendipitously, and they are reported in Experiments C1 and C2.

We attempted to mask target trigrams with patterns that varied in contrast. It was assumed that such masks would show an effect specific to the integration through common synthesis period, on the assumption that as a common occupant of a composite icon, a light grey mask would be less devastating to a black target than a black mask would be. It will be shown, however, that the differential effectiveness of these masks is made manifest in a different manner.

Method. Block-letter consonant trigrams (CCC) of 10 ms exposure were preceded or followed at various target-to-mask onset asynchronies (-80, -50, -20, 0, 10, 20, 40, 50, 60, 80, 100, and 150 ms) by one of three 10 ms duration masks. The masks were photographic reproductions of the backward letter mask described in Experiment A2 and they varied in contrast. They may be characterized as light grey, dark grey, and black patterns on a white background, yielding contrast ratios, respectively, of 1:6, 1:12, and 1:30. The luminance of this white background for targets and masks was 108 cd/m^2.

Four Lake Forest College students were presented 10 trials (five targets to each eye) at each SOA for each shade of grey. The equipment, balancing procedures, and fixation field were the same as those described in Experiment A2.

Results and Discussion. The data were averaged over observers and eye and the results are plotted in Figure 7. An SOA x Mask Contrast x Subjects ANOVA found both main effects to be significant: SOA, $F(11,33) = 14.90, P < 0.01$ and Mask Contrast, $F(2,6) = 9.47, P < 0.025$. The interaction was not significant.

Obviously, our speculation about the locus of the maximum differential influence of mask contrast was in error. Indeed, examination of a graph of the differential effects of the black and light grey masks (Fig. 8) shows that the peak difference occurs at SOA = 40.

Before we try to understand why mask contrast should behave in this peculiar way, the importance of maximum differential masking at SOAs greater than 0 should be noted. The two sources of masking described thus far in the present communication, peripheral integration (e.g., Experiment A1) and central integration (e.g., Experiments

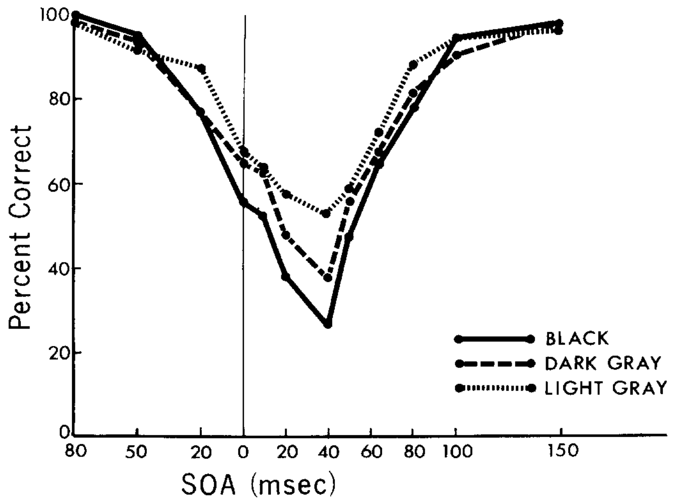

Fig. 7. Relation between target identifiability and SOA for dichoptic forward and backward masking with three values of mask contrast in Experiment C1

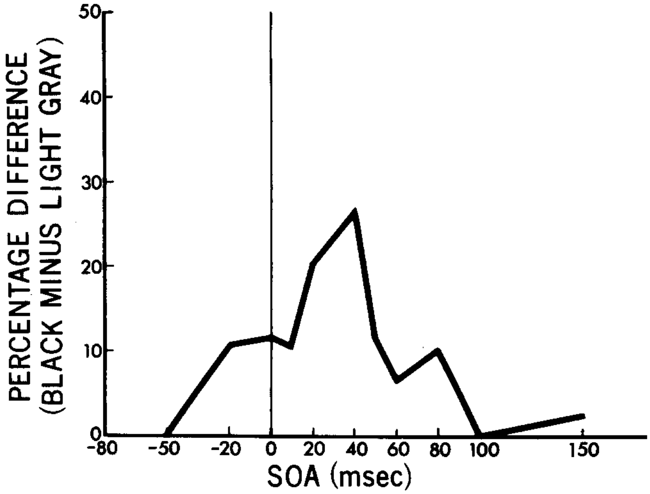

Fig. 8. Computed difference between the BLACK and LIGHT GRAY functions of Figure 7

B1 and B2), yielded maximum differential masking at SOA = 0. To find a variable, any variable, whose primary effect is observed at some onset asynchrony other than zero, suggests that the differential masking resulting from the manipulation of that variable is due to a visual masking process *other* than those processes responsible for maximal differences at simultaneous or nearly simultaneous presentation. This process is taken to be the inhibition of sustained channels by transient channels. It must further be supposed (after Breitmeyer and Ganz, 1976) that contemporaneous with the arrival of the mask's transient signal is the inflow, on the sustained channels, of information relevant to the identification of the target letters. These sustained channels are inhibited and identification of the target is, thereby, maximally impaired.

It was not immediately obvious why mask contrast should seem most important at the nadir of the masking function. However, consideration of possible explanations will be deferred until Experiment C2. This is because Experiment C2 yielded similar and statistically significant results as a function of a different independent variable, and eliminated one good explanatory candidate for the present results, namely, that the maximal difference at SOA = 40 was an artifact of averaging procedures.

Experiment C2

Experiment C2 sought to replicate the finding of maximal differential masking at an SOA other than 0 ms. We observed in Experiment C1 that mask contrast had its primary effect on the masking curve at a target onset to mask onset interval of about 40 ms. In particular, Experiment C2 asked two questions: first, where is the maximal differential masking effect of masks that differ in color[8]; second, do eye dominance effects obscure the locus of the effect of mask color and, by implication, the locus of the effect of mask contrast.

The motivation for examining dominance comes from the potency of the dominance effect reported in Experiment B2. The effect of dominance was so powerful that we might well imagine that the floor and ceiling effects it induces at points in the masking function serve to obscure other differential masking effects at those intervals. We argued that the selective effect of mask contrast at SOA = 40 was important to the specification of a process other than simple integration. However, it is a strong possibility that mask contrast may have exerted its major influence at SOA = 0, only to be negated by eye dominance effects.

Method. Ten Lake Forest College undergraduates participated in an experiment identical in method to the preceding experiment with the exception that black, red, and orange masks replaced the grey masks. The masking patterns were cut out of colored construction paper and pasted on a white background. The pattern of the masks was identical to that used in Experiment C1. The targets were the black block-letter trigrams used in the previous study. Targets and masks had exposures of 10 ms at 108 cd/m^2.

Results and Discussion. Of the 10 subjects, the five who showed the most dominance (defined to be differential masking effects at SOA = 0 between the two eyes) were assigned to the dominant group and the five showing the least dominance were assigned to the nondominant group.

The numbers correctly reported under each mask color (red, black, and orange) were averaged over eyes and observers, and the curves are presented by dominance group in Figure 9. A Dominance x SOA x Color x Subjects ANOVA revealed three significant effects; SOA, $F(11, 66) = 31.20, P < 0.001$; Color, $F(2, 12) = 15.65, P < 0.001$; and SOA x Color, $F(22, 132) = 3.37, P < 0.001$. The color effect says that, on average, black masks yielded more impairment than red masks, and red masks in turn yielded more impairment than orange masks. The interaction simply implies that mask color has an effect specific to particular SOAs.

We note first that the effect of mask color is more general than the effect of mask contrast. That is, color appears to have a more substantial effect over a large range of SOAs than we observed with mask contrast. However, as with the contrast relation between target and mask, the difference induced by changing the color relation does not appear to be symmetric with respect to SOA = 0; the difference is larger in the backward masking situation.

The dominance variable (strong vs. weak) did not enter into any significant effects. This is perhaps due to the weakness of group identity; that is, even nondominant observers showed some dominance. This variability aside, the graphs do demonstrate a

8 In retrospect, while the nominal variable of interest was that of color, the effective variable may well have been intensity (see Sakitt, 1976). It is possible that the variable manipulated in this experiment is the same as that manipulated in the preceding experiment, namely, the intensity contrast between the mask form and the background. Nevertheless, the experiment speaks to the main issue of whether eye-dominance effects are obscuring an effect that is maximal at SOA = 0 ms.

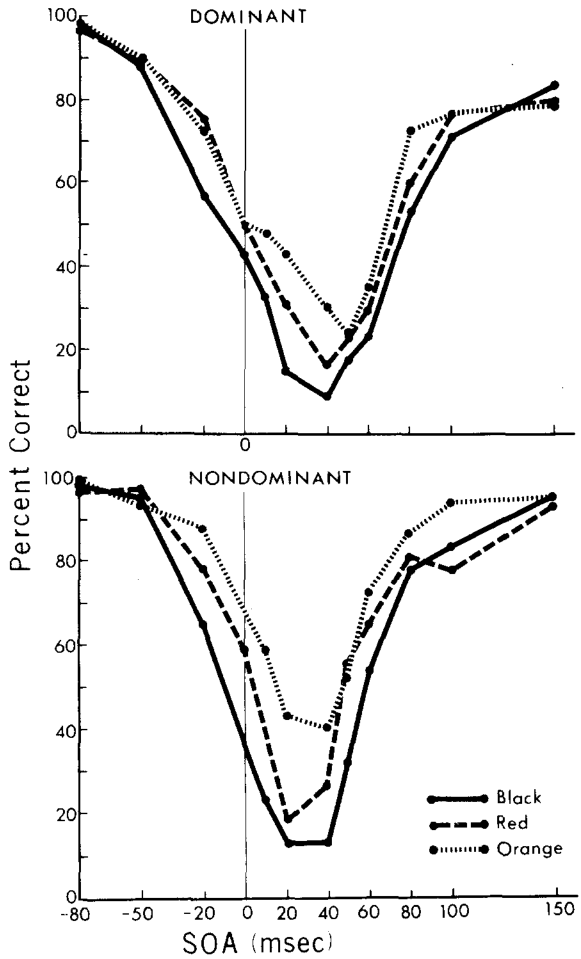

Fig. 9. Relation between target identifiability and SOA for dichoptic forward and backward masking with three values of mask color and with the target presented to observers showing greater and lesser dominance (upper and lower panels, respectively)

trend, on the part of dominance, toward minimizing the differential color masking effects. Consider the examples of 0 and 10 ms SOA. The dominant group shows a differential masking effect of 7% and 15%, respectively, while the nondominant group showed 28% and 36% difference. While it is the case that the dominant group had diminished differential masking at brief SOAs, a substantial difference due to mask color remained.

In summary, varying mask color alters the shape of the curve in a manner similar to varying mask contrast. Both variables seem to be of greatest relevance to the backward masking situation, and in particular, over that backward masking range in which we presume the primary source of masking is not integration through common synthesis. While the effect of neither variable is completely specific to the area around the nadir of the function, the enhancement of their effect in this region suggests to us that the influences on icon fidelity at that point are different from those determining its character in other temporal regions. The present experiment and its immediate predecessor are taken as identifying a second source of masking, namely, interchannel inhibition.

That differential masking can be observed over the range shown (see Figs. 8 and 9) is not surprising, given our arguments and those of Breitmeyer and Ganz (1976), but why these particular variables can induce such an effect is somewhat puzzling. One guess is that the black mask, in comparison to masks of a lesser contrast, elicits a more potent transient signal and exerts a greater inhibitory effect on the sustained channels.

Summary of Experiments A1 to C2: The Constructor Function

At the outset of this enquiry, it was proposed that the first few hundred milliseconds of visual activity could be dichotomized into two relatively distinct, although crudely defined, classes of operations. The first was an icon synthesizing stage (done by a 'constructor') and the second was an icon identification stage (done by an algorist). It is believed that the masking influences revealed in Experiment A1–C2 all bear on the manner of icon construction. It seems appropriate, therefore, to provide a summary of these influences before turning our attention to the temporal constraints on the icon identification stage.

Assuming that certain influences are brought to bear during the synthesis period, it is supposed that the consequences of these influences affect the quality or fidelity of the iconic image. Thus, variables that alter masking effects in the descending portion of the masking curve are thought to affect the accuracy of the internal representation of the target event. Performance, in turn, reflects the algorists ability (or inability) to deal with a poorly articulated iconic image. The present discussion will summarize our current understanding of the causes of iconic 'infidelity.'

The first source of influence on icon accuracy is limited to monoptic or binocular delivery of two visual fields and is owing to interactions of target and mask data in the peripheral visual system. This interaction, which we termed integration through within-net time-sharing, has been examined in great detail in recent years (e.g., Eriksen, 1966; Turvey, 1973); we have, therefore, made but a passing note of it (Experiment A1). Our account of how peripheral interactions impair icon fidelity has been along traditional lines, indeed very close to Eriksen's (1966) original proposition of luminance summation/contrast reduction. Put simply, energies sum, and therefore the signal-to-noise ratios of the incoming events are lowered; increasing the energy of one lowers the signal-to-noise ratio of the other.

There is another sort of integration, or mixing, that is more easily observed in the dichoptic than in the monoptic situation. In this case, however, it is forms (features or spatial frequencies) that mix, rather than energies (Experiment A1). This mixture has been described as integration through common synthesis, in the sense that figural or spatial frequency aspects of two visual fields are combined to yield an iconic representation that embodies both target and mask. Forward masking is taken to be a relatively unconfounded estimate of this source of perceptual impairment (Experiment B1). Backward integration, in the absence of interchannel inhibition, is not as easy to measure, although it has been inferred from the locus of eye dominance effects (Experiment B2) that there is an integrative backward counterpart that is equal in magnitude to forward integrative effects. From the symmetry of these two functions (Fig. 6), it has been argued that within a very narrow range of SOAs there is one integrative function that is indifferent to the order of presentation of two visual fields.

As the onset asynchrony is increased, the order of the two fields becomes an important factor in determining which field will dominate the iconic composite. This range of SOAs presumably represents the range of intervals over which some data on the first of two successive fields are made unavailable through interchannel inhibition. Thus, the integration of the two visual fields at this point is *not,* as above, the integration of two equally represented data sets. The two factors, simple integration at SOAs very close to 0 ms, and integration plus data deletion at longer SOAs, occasion the nonmonotonic backward masking curves that have been characteristic of the results presented thus far.

To buttress the argument that the source of masking at SOA = 0 and at the nadir of the dichoptic masking function are not the same,independent variables that show effects more or less specific to each of those temporal ranges have been reported. The identification of targets delivered to a dominant eye is maximally better than those delivered to a nondominant eye if the two visual fields are simultaneous, while the identification of a black target followed by a grey (or orange) mask will be maximally superior to that of a black target followed by a black mask *at an SOA of 40 ms or more.*

It has been argued (Breitmeyer and Ganz, 1976) that these two sources of central masking provide a sufficient description of all central masking effects. As such, the Breitmeyer and Ganz theory may be characterized, in masking parlance, as an Integration theory of masking, rather than an Interruption or Integration/Interruption theory (cf. Kahneman, 1968). The twist in their integration theory, the preemption of sustained channels by transient channels, makes the theory invulnerable to the usual criticism of a strict integration view: that backward central masking is far more pronounced than forward central masking.

Such a two-factor account of central masking is graphically summarized in Figure 10. One function, symmetrical about SOA = 0, is meant to characterize integration through common synthesis. The second function represents the inhibition by a transient

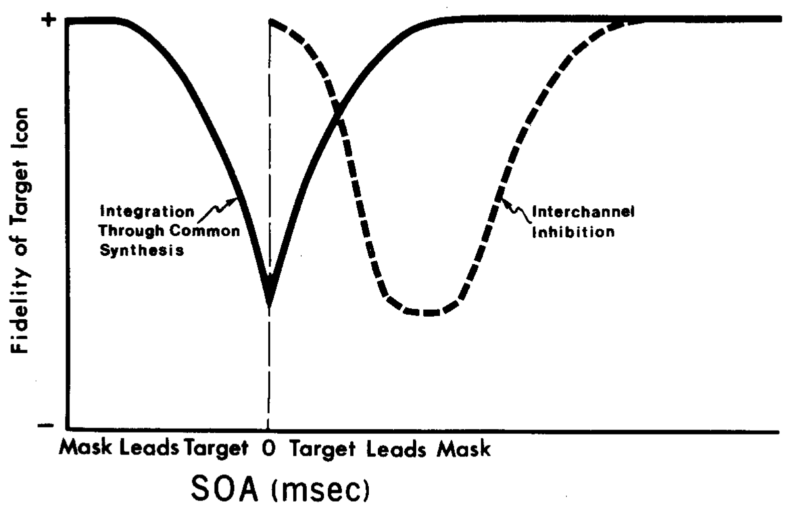

Fig. 10. A two-factor account of central masking

pulse of sustained channels carrying spatial frequency information *relevant to letter identification*. We limit the generality of the latter curve because, as Breitmeyer and Ganz (1976) point out, different tasks (detection, recognition, clarity judgments, etc.) probably rely on the successful input of different spatial frequencies. Thus, the temporal location of the nadir of this function probably varies from task to task. The net of these two curves presumably describes the fidelity of the relationship between an icon and the target that it represents. The two-factor theory, then, would propose that all functions relating letter identifiability to SOA could be obtained by raising or lowering, in its entirety, one or both of these components. Indeed, if we peruse the results of Experiments A1-C2, we see that selective manipulation of these two hypothetical functions accounts nicely for those results.

In spite of this apparent fit, the present communication argues for a third source of central masking: an abrogation of the attention of an algoristic central processor by the second of two temporally distinct visual fields. At issue is whether the fidelity of an icon to a target field can account for the entire family of central masking functions. A deeper issue, however, is whether over the temporal range in which visual masking occurs, one should speak of separate and distinct icons, or of a single icon that is over this temporal range forever becoming a better representation of the visual stimulation. A masking theory that includes interruption would most likely promote the idea of distinct icons; an integration view would be happy with a single and lengthy synthesis.

We proceed to question the plausibility of the integration-alone view by investigating another aspect of visual integration, its phenomenology.

D. Phenomenal Consequences of Dichoptically Opposed and Successive Visual Fields

Experiment D1

The integration of two independently presented visual fields into one phenomenal event can be inferred from two distinct experimental situations. The first, of course, is masking. The second is the identification of some form that exists in a composite of two visual fields, but in neither field alone (e.g., Eriksen and Collins, 1967). In both cases, integration appears to be maximal with concurrent presentation of the two fields. As the two fields are temporally separated, the extent to which they blend decreases.

In keeping with the distinctions made earlier, it is suggested that integration of two visual fields may occur at more than one neuroanatomical locus. Luminance summation, for example, is presumed to operate in the peripheral visual system because its effects are primarily limited to monoptic presentation (Experiment A1). It was supposed, as well, that there is central integration in which forms (features or spatial frequencies) are summed, but not energies. Estimates of the interval over which there is central integration vary widely from task to task and can be dramatically shortened by extended practice and knowledge of results. One of the more consistent ways of measuring this interval is by dichoptic presentations of displays containing binocular 'depth' information. When stereograms are viewed, for example, a form appears in depth, although examination of the individual dot patterns reveals neither form nor depth. If the two patterns are presented briefly, the form-in-depth will be seen or not seen as a function of the temporal lag between the stereograms (Dodwell and Engel, 1963). The estimates of the interval over which such integration can occur range from 40 ms to

70 ms among individual observers (Ross and Hogben, 1974; Michaels, Carello, Shapiro, and Steitz, 1977).

If two visual fields truly integrate into one at brief temporal separations, it should be the case that observers cannot tell the temporal order of the two fields, nor should they be able to distinguish the presentation of one field from the presentation of two fields. Experiments D1 and D2 are simple demonstrations of these effects.

Method. Experiment D1 attempted to determine the SOA value at which observers could correctly judge the temporal order of two dichoptically presented displays. Two slides, one containing a disjointed horizontal bar (--) and one containing a disjointed vertical bar (¦) were prepared. When the two bars were aligned, they formed a 'plus' sign. The areas of overlap of the two bars were removed so that the 'plus' had an open square at the point of intersection.

The two bars, the horizontal and the vertical, were presented for 10 ms at 34.3 cd/m^2 at various SOAs (10, 20, 40, 50, 60, 70, 80, 100, and 150 ms). Four Yale University undergraduates were asked to report which of the pair (the horizontal or the vertical) appeared to come first on each of 18 blocks of 10 trials. Knowledge of results was not given. In the first nine blocks two observers received the leading event to the right eye and the lagging to the left (one observer with SOA increasing by block and one with SOA decreasing by block), and the second nine blocks found the left eye leading with the opposite order. Observers 3 and 4 were given the bars in an order precisely reversed from that given to subjects 1 and 2 respectively. Each block of 10 trials contained a random arrangement of five trials in which the horizontal bar preceded the vertical bar, and five trials in which the vertical bar led the horizontal bar.

All presentations were done by the tachistoscope described in Experiment A1. The fixation fields and their luminance were as described for that experiment.

Results and Discussion. The percentages of trials on which observers could correctly judge the temporal order of the two bars are plotted as a function of SOA in Figure 11.

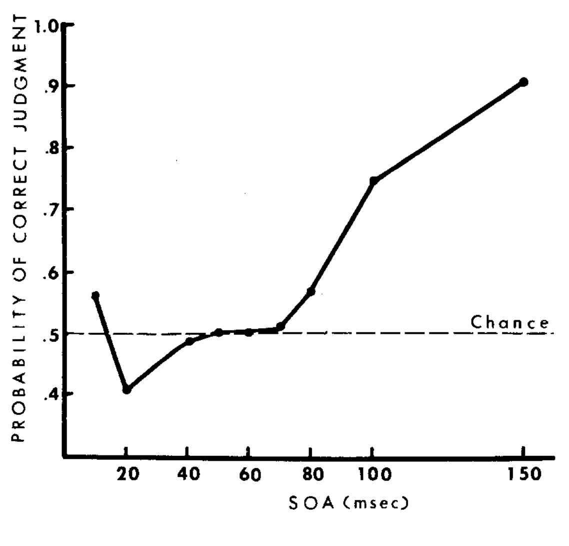

Fig. 11. Probability of correctly judging the order of two differently oriented bars presented dichoptically at various SOAs in Experiment D1

Inspection of Figure 11 reveals that over a range of relatively brief SOAs, observers cannot correctly order the bars in time. As the interval increases beyond 70 ms, performance improves dramatically.

It is supposed that integration yields the perceptual composite that results either in dichoptic masking or in the identification of a complementary pattern, depending on task parameters. We propose that the same operation obscures the temporal ordering of two visual events. When two visual fields are delivered within the synthesizing period, the algorist's decision must be made on *one* synthesized representation.

The various dependent measures described above can be accounted for by an integration hypothesis. However, it is questionable whether the phenomenal experience is consistent with these results: do observers actually see but one event when two have been presented in close temporal proximity?

Experiment D2

Experiment D2 examined the phenomenology of central integration from another perspective. It might have been the case in Experiment D1 that observers saw two separate visual fields but were simply unable to order them. Experiment D2 asked the observers to report, simply, whether one or two things occurred.

Method. A Gerbrands three-channel tachistoscope modified with polarizers for dichoptic viewing was used to present horizontal and vertical bars. The bars described in Experiment D1 were prepared on 12.7 by 17.6 cm white cards. The viewing field of the tachistoscope was 7^{o} horizontal by 5^{o} vertical. One channel of the tachistoscope constantly projected a faint but discernible dot for fixation. The two cards, the horizontal and vertical bars, were presented for 10 ms at 17.15 cd/m^2.

Four University of Connecticut undergraduates were shown the two bars under conditions of simultaneous presentation. They were told to label this experience, that of a plus sign, as 'one event,' and the experience of two bars, one vertical and one horizontal, as 'two events.' The experiment then proceeded; observers were asked to report how many events they experienced – one or two. In fact, on all trials two visual events, that is, two bars, were delivered.

Twenty trials were given at each of 10 SOAs (10, 20, 40, 50, 60, 80, 100, 120, 140, and 180 ms) randomized in blocks. On one half of the trials the horizontal bar led, and on the other half, the vertical bar led. Eye order was balanced within observers.

Results and Discussion. The percentage of the time that observers saw one or two events was computed. The averages over observers are plotted as a function of SOA in Figure 12. Again, there is very poor performance up to and including 60 ms. Above that value observers begin to detect the presence of two distinct visual fields.

The phenomenology of integration closely parallels the results observed using other dependent measures. (This does not go without saying, as there are situations in which the phenomenal report is at variance with other dependent measures – e.g., Fehrer and Raab, 1962.) It appears that when two events are presented in very close succession, subjects cannot even detect the presence of two events, let alone determine which came first.

The important point to a theory of masking, however, is not the range of intervals over which two visual fields behave phenomenally as one, but the range over which they behave phenomenally as two. There seems to exist a range of intervals over which

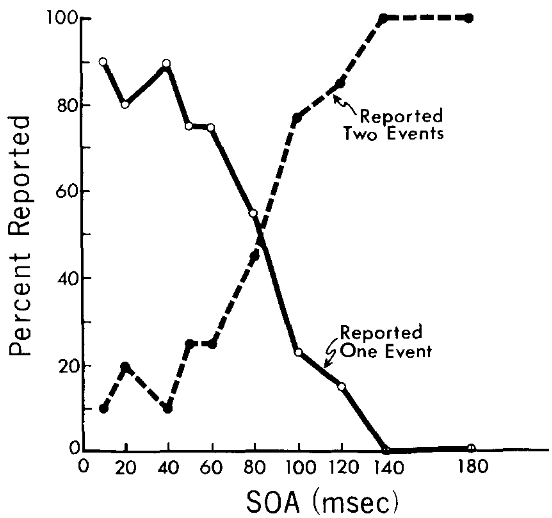

Fig. 12. Percentage of times two differently oriented bars presented dichoptically were judged as one or two events as a function of SOA in Experiment D2

observers could report on the presence of two temporally distinct occurrences, but fail to determine the identity of the first occurrence. That is, there are onset-to-onset times (perhaps 60 to 150 ms) that yield both backward masking and phenomental duplexity. It appears, then, that masking can be observed in the *absence* of any phenomenal integration. If this is true, it must be supposed that a principle other than integration or composite iconic synthesis is necessary for the explanation of central backward masking. Support for this statement will now be given.

E. The Replacement Principle

Experiment E1

In the phenomenology of viewing two visual fields in rapid succession, there is support for the idea of two distinct iconic representations when fields are delivered at appropriately long onset-to-onset times. In the backward masking arrangement, the first icon primarily represents the target and the second primarily represents the mask. In addition, it is argued that the latter icon replaces the first as the principal object of algoristic attention and thereby interrupts processing of it; in short, the mask icon imposes a temporal constraint on the algorist. To argue along these lines is to argue for the insufficiency of a two-factor integration theory of central masking (Breitmeyer and Ganz, 1976).

If icon replacement is a legitimate principle, it would be expected that the ascending portion of the dichoptic masking function be shaped to some extent by variables relating to iconic readout, more precisely, by nonenergetic and nongeometric variables relating to pattern recognition. Support for this expectation is sought in the use of various parameters of stimulation that selectively manipulate the dichoptic masking curve; a successful manipulation of the ascending part of the curve, in the absence of effects at SOA = 0 ms and at the curve's nadir, would imply a two-field interaction different from integration through common synthesis and interchannel inhibition.

If, at large SOAs, the constraint on the algorist is truly one of insufficient processing time for the first icon, then variables that affect speed of recognition should show an effect specific to the ascending part of the curve. As noted above, we intuit that higher-order (that is, nonenergetic and nongeometric) variables are relevant to a speed of recognition distinction. Experiments E1, E2, and E3,[9] then, are concerned with such higher-order variables and, in particular, they examine distinctions between words and nonwords and distinctions between presentation to the left and right hemifields. We begin by comparing the identifiability, under masking, of words and nonwords.

Since the time of Cattell (1886) it has been recognized that letter configurations that form words are identified more accurately than random letter configurations. Precisely what it is about words that makes them more easily identified is still an issue, although a variety of probable contributors have been implicated [familiarity (Eichelmann, 1970), meaningfulness (Reicher, 1969; Wheeler, 1970), number of pronounceable units (Gibson, Bishop, Schiff, and Smith, 1964), spelling regularities (Baron and Thurston, 1973), letter frequency (Engel, 1974), syllable frequency (Claxton, 1975), and letter-position frequency (Mason, 1975)]. Our purpose, however, is not to assay these factors, but rather, it is to ask where in the central masking function the quality of being a word shows its influence.

There is increasing evidence that words have features above and beyond the features of their component letters, and that perceivers use these features to identify the words and as an aid to identifying the letters (e.g., Johnson, 1975). If the assumption is that one consequence of dealing with words is the ease or speed with which constituent letters are recognized, then it might be predicted that the slope of the ascending portion of a dichoptic backward masking curve is steeper for words than it is for nonwords. On this prediction, the present experiment compared, among other things, the dichoptic masking functions of consonant-vowel-consonant (CVC) words and consonant-consonant-consonant (CCC) nonwords.

In addition to asking whether and where in the masking function these letter-combinations differed as targets, it was asked whether and where in the masking function they differed as masks. Insofar as the geometry of letter combinations that are words and the geometry of letter combinations that are nonwords is the same, it would not be expected that mask type be of influence in integration through common synthesis. Nor would it be expected to manifest itself as a significant variable in interchannel inhibition; the suppression value of transient channel pulses should be indifferent to the word/nonword distinction. However, there is uncertainty with respect to the influence of mask type on the phase of masking that reflects the replacement principle. Inasmuch as the replacement principle is an attentional concept, and inasmuch as we may treat attention as the allocating of processing resources or of algorithms (cf. Neisser, 1967; Hochberg, 1970; Norman and Bobrow, 1975), then it is a plausible claim that two things will interfere to the extent that they require common algorithms. This point of view, with reference to masking, has been expressed elsewhere: 'Masking arises...posticonically, not because of icon replacement, although that may occasionally

[9] Experiments E1, E2, and E3 were conducted as part of a dissertation submitted by the first author in partial fulfillment of the degree, Doctor of Philosophy, at the University of Connecticut (Michaels, 1974).

be true, but because discovering what kind of object the mask is may require the services of decision nets...which are presently engaged in discovering what kind of object the target is' (Turvey, 1973, p. 47). It is possible, therefore, that a word mask, say, might impede the processing of a word target more than that of a nonword target; assuming, of course, that the processing evoked by words and nonwords differs.

In summary, it is conjectured that the ascending portion of the central masking function reflects, in very large part, the degree of undivided attention that the algorist can give to the target icon. The duration of undivided attention is directly proportional to the interval between target and mask icons. Relatedly, it is conjectured that where letter configurations differ in speed of recognition, that difference should be revealed as a local effect in the ascending part of the dichoptic or central masking function. Insofar as words and nonwords may be thought to engage different identification algorithms, but not to differ geometrically, a differential effect of word and nonword masks might be found in the ascending part of the function, but not elsewhere.

Method. A target trigram (either a CVC-word or a CCC) was followed dichoptically, at varying onset-to-onset times by one of two types of masks (a CVC-word or a CCC). The letters in the mask field overlapped those in the target field.

The letter strings were prepared as follows. All C_1VC_2 trigrams, in which C_1 was different from C_2, and which had a frequency of usage of greater than 10 per million, were selected from the Thorndike and Lorge (1944) norms. One hundred words were selected according to frequency, highest first, except that an attempt was made to minimize those having the same consonants (e.g., bag and bug). Also, words that contained one of the substitution consonants (see below) were not included in the 100-item set. The 100-member CCC set was constructed from the word set by making a one-to-one substitution of the vowel by a consonant (k for a, q for e, j for u, z for o, and v for i). The lower case letters were 0.8° horizontal by approximately 1.2° vertical, with a horizontal separation of $.3^{\circ}$ of visual angle.

Two Yale University undergraduates and two graduate students were recruited as subjects. Each participated in four separate 15-min sessions. In each session, a subject received one target-type to one eye; mask type and SOA were manipulated within each session. (Eye was balanced to permit an averaging out of any effect attributable to eye dominance.) Two subjects began with CVC word targets in Sessions 1 and 2 and ended with CCC targets in Sessions 3 and 4. The other two subjects received the reverse order. The eye receiving the target was counterbalanced across sessions. On two of each subject's sessions, SOA increased in blocks of 10 trials and in the other two it decreased. Within each 10-trial block there were five CCC masks and five word masks arranged in a random order. Ten SOA values were used (0, 10, 20, 40, 50, 60, 80, 100, 150, and 200 ms).

Subjects fixated a centrally located and constantly illuminated point of light on a black background. Both target and mask fields were presented for 10 ms at 34.3 cd/m^2 on the six channel Scientific Prototype tachistoscope. Subjects were instructed to report as many of the six letters (three in the target and three in the mask) as possible.

Each set of slides from the CVC word set and CCC nonword set was divided in half. Two sets, each containing 50 CCCs and 50 words were formed; one was arbitrarily designated as the target set and the other was designated as the mask set. The mask set was then randomized into blocks of 10, such that there were five words and five CCCs in each block. The two sets of target letter strings, CCCs and words, were individually randomized with the restriction that no item was ordered such that it and the letter string that would be used to mask it, shared a common letter.

Results and Discussion. The response sheets were scored only for number of *target* letters correctly reported. The scores for each of the four target-type by mask-type combinations were averaged across eye. Individual and group results are presented as a function of SOA in Figure 13. As can be seen in the figure, all subjects demonstrated that word targets are superior to CCC targets at SOAs of greater than 40 ms. These data were subjected to a Target-type x Mask-type x SOA x Subjects ANOVA. Three significant effects were observed:

(1) SOA, $F(9, 27) = 14.11, P < 0.01$
(2) Target-type, $F(1, 3) = 34.4, P < 0.01$
(3) SOA x Target-type interaction, $F(9, 27) = 4.06, P < 0.01$.

In relation to Figure 13, the results of these observations appear rather straightforward. At very brief SOAs, the four curves in the averaged data are virtually overlapping; however, the curves eventually diverge, and we find far superior performance on the word targets. Performance on the CVC words appears to asymptote at an SOA of 100 ms; the CCCs in contrast, have not begun to asymptote at 200 ms. Finally, as the figures indicate and the analysis of variance affirms, the nature of the mask (CVC word or CCC) seems unimportant.

The results of Experiment E1, then, stand in broad agreement with the theoretical arguments that have been presented. As targets, words and CCCs yield differential performance, but that difference is only observed after the point of inflection in the curve. As has been previously argued, the specificity of this effect suggests that the constraints on performance in this portion of the curve differ from the constraints imposed elsewhere. In particular, the descending part of the curve is seen as arising from an inability to identify components of a commonly synthesized representation of target and mask. The point of inflection in the curve represents a situation in which there exists not only some integration, but also an inhibition of the sustained channels (carrying specific form data on the target) by a transient channel (signaling the onset of another contoured event). As the arrival of the mask is delayed beyond that point of inflection, the performance curve will yield gradually to the effects of higher-order variables. It was intuited that processes that affect the speed or efficiency of pattern recognition would have an effect specific to the ascending part of the function. It is now apparent that the word/nonword contrast induces the effect that had been expected.[10]

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[10] This experiment and the two that follow are significant to research on word perception. Suppose that an investigator wishes to determine whether a given variable affects the perception of letter strings and for this purpose he or she chooses to use a backward masking paradigm (e.g., Reicher, 1969; Wheeler, 1970). The investigator might then arbitrarily choose an interval between the exposure of the letter string and the onset of the mask and ask whether identification or recognition performance under these conditions is affected by the variable in question. Suppose that the variable proves to be insignificant. Is it because the variable does not affect the perception of letter strings, or is it because the interval chosen is not optimal for revealing the given variable's effectiveness? In experiments using the backward masking paradigm, one ought to design the

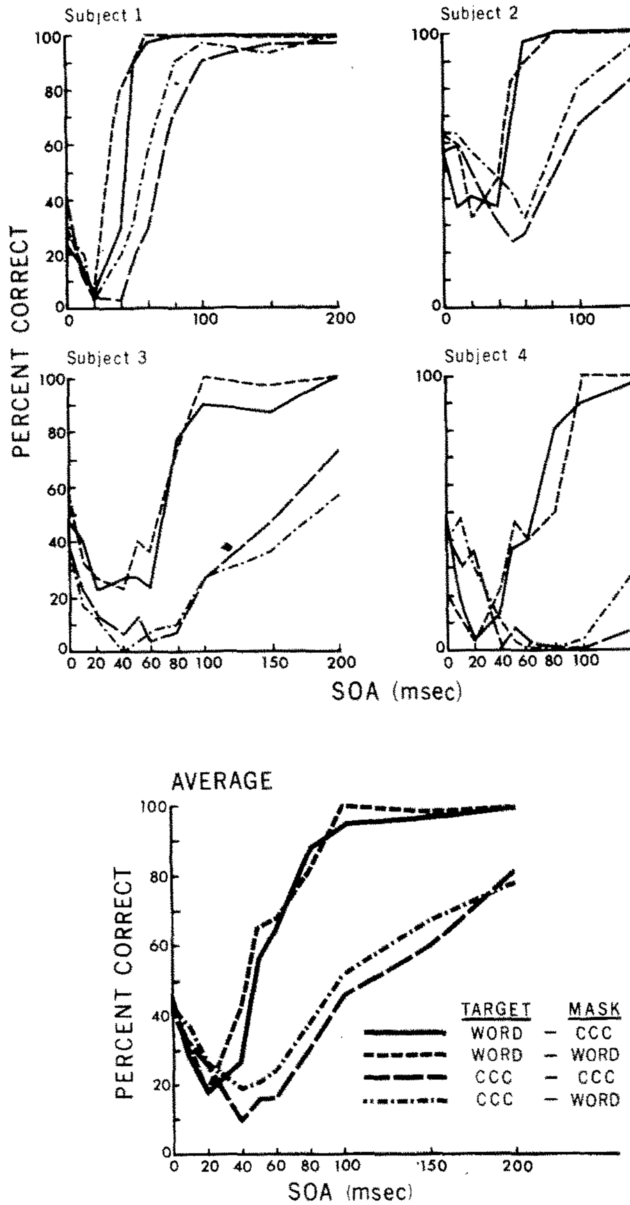

Fig. 13. Individual and average relations between letter identifiability and SOA for three-letter words and consonant trigrams opposed dichoptically by three-letter words and consonant trigrams in Experiment E1

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experiment so as to trace out the masking function befitting the conditions of observation. Spurious conclusions may follow if the full range of SOAs is not examined. We take this comment to be consonant with the admonitions of Smith et al. (1976) and Purcell, Stanovich, and Spector (1978) to be wary of the influence of non-linguistic variables on the processing of language by eye.

One additional feature that distinguishes performance on CCC targets and CVC word targets is that the nadirs of their masking functions occur at different SOAs. Breitmeyer and Ganz (1976) proposed that the nadir will occur at the point of contemporaneous arrival of a mask's transient signal and the spatial frequencies of the target that are most relevant to the task at hand (detection, recognition, etc.). Different tasks, therefore, should have masking curves with different low points. However, a comparison of the curves for dominant and nondominant eyes (Fig. 5) reveals that the nadir can be determined additionally by an interplay of interchannel inhibition and integration through common synthesis. The present experiment further suggests that differences in the temporal course of iconic processing may influence the location of the nadir. Perforce, it may be concluded that the location of the nadir is not a *pure* indicant of any special neural or psychological process.

As observed, CVC words and CCC nonwords did not differ in their masking effects on words and nonwords. This result might be taken to mean that an aftercoming icon preempts algoristic attention completely regardless of its relationship, in processing terms, to the contents of the preceding icon. On the other hand, it may be concluded that the algorithmic support for word and nonword perception is the same; in which case no difference in masking influences would be predicted. Evidence favors the latter interpretation. Merikle (1977) has shown that letter targets are impaired more by letter masks than by digit masks. This difference in mask effectiveness, moreover, occurs only at long onset asynchronies. The replacement principle identifies a biasing of algoristic attention to the later of two successive visual fields and we interpret Merikle's experiment to mean that the biasing is sensitive to how the target and mask relate in terms of their algorithmic needs. Other relations between target and mask may provide additional support for this position (cf. Uttal, 1971; Jacobson, 1973; Merikle, 1974; Jacobson and Rhinelander, 1978; Hellige et al., 1979).

Experiment E2

Experiment E1 revealed that a distinction between performance on CVC words and CCCs emerges relatively late in central visual activity, as defined by the dichoptic masking function. We supposed that in this late phase, words were somehow processed or recognized differently from nonwords. We may well suppose, therefore, that other sources of processing differences should reveal, in like fashion, an effect specific to relatively long onset-to-onset intervals. By many theoretical accounts, hemifield differences in recognition reflect differential processing.

A bare-bones account of visual hemispheric asymmetry acknowledges two fundamental premises: first, that the left hemisphere is the chief proprietor of mechanisms that underlie the perception and production of language; second, that the organization of the visual system is such that material presented in the left visual field is projected to the right cerebral hemisphere, while material presented in the right visual field is projected to the left hemisphere. This combination promises a perceptual advantage for verbal material presented in the right visual field and thus to the left (language) hemisphere. A variety of studies (e.g., Kimura, 1966; Mishkin and Forgays, 1952; Heron, 1957) have observed just such an advantage in favor of the left hemisphere. In addition, it is generally believed that there is a right hemisphere superiority for visuo-spatial stimulation (Kimura, 1966; Geffen, Bradshaw, and Wallace, 1971). While these formulations are probably correct, they do not, of course, exhaust the list of variables that have been shown to affect the magnitude and direction of perceptual asymmetries. Post-exposural scanning associated with reading habits (e.g., Harcum and Filion, 1963; Krueger, 1976), control of fixation (McKeever and Huling, 1971), serial vs. parallel processing (Cohen, 1973), and attentional bias (Kinsbourne, 1970) have all been implicated as contributors.

In spite of their variety, all of the variables that underlie laterality effects appear to be relatively higher-order, involving processing modes, attentional bias, and strategies. Also, in that laterality effects have been shown to be post-iconic (Marzi et al., 1979), a laterality difference, such as a right visual field advantage for verbal material, was expected to be realized in the dichoptic masking function at relatively long onset-to-onset intervals. It would not be expected that such a difference be manifested in those portions of the masking curve that are supported by integration through common synthesis and interchannel inhibition.

To test the notion that perceptual asymmetries (in particular, a left hemisphere advantage for verbal material) are limited to the ascending portion of the J-shaped function, trigram targets were unilaterally presented to the left or right visual field and were followed dichoptically by a second (masking) trigram.

Method. The trigrams used in Experiment E1 were rephotographed so that on one half of the slides the center letter of the trigram was positioned 2^o to the left of fixation, and on the other half it was positioned 2^o to the right of fixation. Each letter was, on average, 0.3^o wide by 0.6^o high. The letters were separated by 0.15^o. The slides were randomized into paired blocks of eight: each of two target types (CCCs and words) for each of two mask types in each of the two visual fields.

Four Yale University undergraduates received five blocks (40 trials) at each of 10 SOAs and each of two eye combinations (target to left, mask to right; target to right, mask to left) on the six-channel tachistoscope. As in Experiment E1, SOA (ascending or descending order) was counter-balanced within subjects and eye order was balanced across subjects.

Because pilot work had indicated that these small letter arrangements were somewhat difficult to identify when presented for 10 ms, exposure duration was increased to 20 ms for both target and mask displays. A luminance of 34.3 cd/m^2 was used.

In summary, the design used in Experiment E1 held for both the left and right visual fields. The entire 800-trial procedure lasted about 2 h including a 15-min rest at the halfway point.

Results and Discussion. It has been known for some time that subjects are often inclined, when guessing, to report a word even if the displayed material is not a word (e.g., Pillsbury, 1897). To minimize this bias, only the first and last letters in the target trigrams were scored. By virtue of the manner in which the trigrams were created (see Experiment E1), the CCC trigrams and the CVC words were identical – except for the middle letter.

The results, averaged across eye, are plotted in Figure 14. An SOA x Visual Field x Mask-type x Target-type x Subjects ANOVA revealed several interesting results. An examination of those effects in which laterality was not a factor follows. In replication of Experiment E1, SOA and Target-type as well as their interaction, were significant sources of variance:

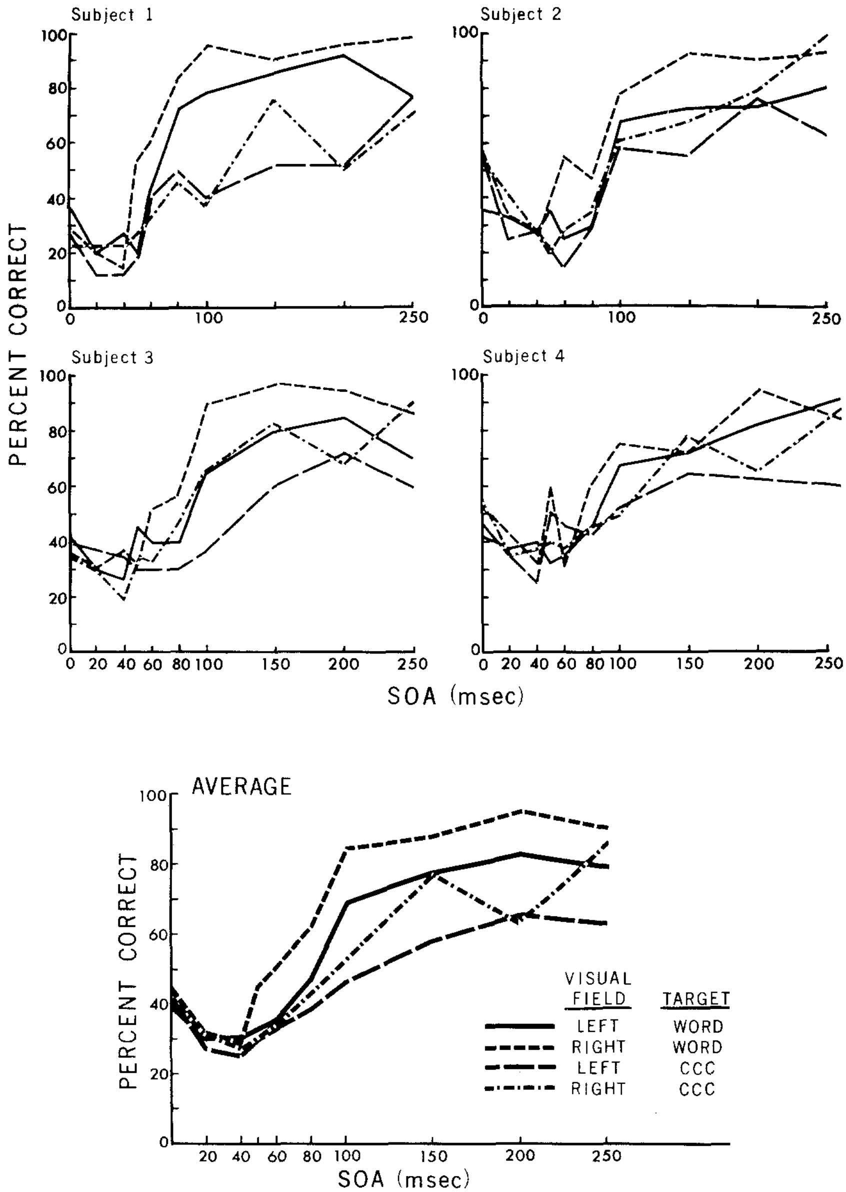

Fig. 14. Individual and average relations between letter identifiability and SOA for three letter words and consonant trigrams under conditions of dichoptic masking with the target presented to either the left or right visual field in Experiment E2

$F(9, 27) = 39.85, P < 0.01$; $F(1, 3) = 14.51, P < 0.05$; and $F(9, 27) = 4.65, P < 0.05$, respectively.

The analysis of variance revealed only one other effect in which laterality was not involved, an SOA x Target-type x Mask-type interaction. We observed that mask type can affect performance. Examination of the relevant curves (not presented) reveal that at very large SOAs, performance in the CCC-CCC condition was depressed. This observation runs contrary to the results discussed in Experiment E1 where it was observed that CCCs and words were equally effective masks. However, given the temporal locus of this effect, it was presumed that the limitation on the system is a memorial, rather than a perceptual one; six letters are just harder to remember than one word and three letters, or two words. In any case, the fact that this effect did not interact with hemisphere, $F(9, 27) = 1.18$, suggests that the hemisphere effects reported below are not attributable to differences in short-term memory.

Regarding laterality effects, the first observation to be made is that there was a significant main effect of hemisphere, $F(1, 3) = 38.80, P < 0.01$; from Figure 14 it can be seen that performance for letter strings presented to the left hemisphere (right visual field) was superior to that for letter strings presented to the right hemisphere.

Although the Visual Field x SOA interaction was not significant, the predicted trends (similar performance at brief SOAs and different performance at longer SOAs) seem to be present in the averaged data (bottom panel of Fig. 14). An inspection of the curves for individual observers also reveals these trends. However, the difference in overall curve shape among observers (cf. Ss 1 and 4, for example) is notable; this difference contributes to the mean square error, and thus, to the lack of significance. Although the analysis of variance suggests that the field by SOA interaction is not entirely straightforward, the curves (and the significance of this interaction in Experiment E3) do provide tentative support for the conclusion that hemispheric differences are limited to the domain of the replacement principle.

There is another laterality effect revealed by the present experiment that is especially intriguing from the perspective of the theory of hemispheric differences, but which is not germane to masking issues. As such, the discussion and experiment that follow may be of greater interest to students of hemispheric specialization than to students of masking.

Our ANOVA revealed a Target-type x Visual Field (hemisphere) interaction, $F(1,3) = 10.99, P < 0.05$; Table 1 presents the means relevant to that interaction that may be summarized as follows: while a performance difference between CVC words and CCCs was observed for both hemispheres, the difference was greater in the left hemisphere. That is, whatever the factor or factors that distinguish CVC words from CCCs, both hemispheres seem to benefit; the left hemisphere, however, takes greater advantage of that information.

It should be noted that most laterality studies compare relative performance of the two hemispheres on detection, decision, or recognition tasks. The present discussion,

Table 1. Experiment E2: Percent correct as a function of target-tape and hemisphere over SOA

Target-type	Hemisphere	
	Right	Left
Words	35	41
CCCs	29	32
Difference	6	9

on the other hand, couches laterality questions in the following form: under what circumstances is the left hemisphere better than itself, and do these circumstances differ from the circumstances in which the right hemisphere differs from itself. Given this formulation, we might ask what are the distinctions between CVC words and CCCs that are relevant to the left and right hemispheres? Experiment E3 examined in more detail the factors underlying the observation that this distinction is more important to the left hemisphere.

Experiment E3

The present experiment is a brief digression from masking effects per se into the nature of the variables that yielded perceptual asymmetry in Experiment E2. In particular, we wondered what it was about CVC words (as opposed to CCCs) that was advantageous to the left hemisphere.

There are, of course, many distinctions that can be made between CVC words and CCCs, and several were enumerated in the introduction to Experiment E1. One distinction, the number of pronounceable units[11], seemed to represent a promising candidate. Experiment E3 investigated the notion that the number of pronounceable units is the source of the CVC word/CCC differences observed in Experiment E1 and E2. Specifically, if meaning were eliminated or at least minimized, by presenting CVC nonwords rather than words, would the same differences that we observed in those two experiments emerge again?

Method. The set of 100 CVC nonwords was constructed as follows: a table of bigram frequency was generated from the list of 100 words employed in Experiments E1 and E2. The CVCs were constructed to match these bigram frequencies. Familiar abbreviations (GOP) and names (NED) were not included. This procedure also preserved, of course, the frequency of initial and final consonants. The preparation of the slides bearing these trigrams was identical to that described in Experiment E2.

The two target-types, CCCs and CVC nonwords, dichoptically preceded a word mask at varying onset-to-onset times. The CCC targets and the word masks were the same slides used in Experiment E2. Pre- and post-tests were used to determine if in the absence of a masking field the targets were equally identifiable. With the exception of the latter, the procedure and conditions of viewing employed with the four naive subjects were identical to those employed in Experiment E2.

Results and Discussion. The results of the pre- and post-tests revealed no significant differences among the different letter strings. These means were 95%, 93%, 87%, and 94% correct for the CCC-right (visual field), CVC-right, CCC-left, and CVC-left conditions, respectively.

The masking results, averaged across eye and subjects, are presented in Figure 15. An SOA x Visual Field x Target-type x Subjects ANOVA revealed three significant effects. Once again, SOA was a significant source of variance, $F(9, 27) = 21.14$, $P < 0.01$.

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11 We wish to thank Alvin Liberman for reminding us that a trigram such as SFN is not unpronounceable, but rather, that it requires three syllables to be pronounced in contrast to SIN which requires one. Hence, the expression 'Number of pronounceable units' is used in preference to the conventional distinction of pronounceable and unpronounceable.

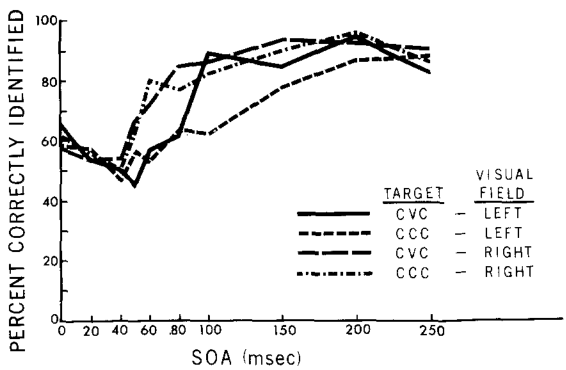

Fig. 15. Relation between letter identifiability and SOA for consonant-vowel-consonant nonwords and consonant trigrams under conditions of dichoptic masking with the targets presented to either the left or right visual field in Experiment E3

The SOA x Field interaction was also significant, $F(9, 27) = 3.46, P < 0.05$, supporting the earlier claim that the locus of the hemisphere effect is specific to certain portions of the curve, and, in particular, specific to the ascending part.

A main effect of Target-type was observed, $F(1, 3) = 18.30, P < 0.05$, and the results plotted in Figure 15 suggest that Target-type is only effective in the right hemisphere, even though the interaction (Field x Target-type) did not reach significance. The curve implies an insensitivity on the part of the left hemisphere and a sensitivity on the part of the right hemisphere, to the number of pronounceable units. These results could suggest two conclusions regarding the variables that affect performance in the left and right hemispheres. First, it appears that a two-factor account of the CVC word/CCC x Field interaction reported in Experiment E2 is supported. That is, that one difference between CVC words and CCCs (number of pronounceable units) is important to the right hemisphere and *another* (perhaps meaningfulness) is important to the left hemisphere.

Two additional experiments were conducted which attempted to confirm the relevance of meaningfulness of letter strings to the left hemisphere and its irrelevance to the right. Both tended to support that hypothesis, but both revealed only marginal statistical significance and for this reason are not reported. It appears, in general, that laterality effects in the masking of verbal items are difficult to demonstrate reliably; even when they emerge in a fairly robust form, extended practice can make them disappear (Ward and Ross, 1977).

Experiment E4

Experiments E1, E2, and E3 lend support to the claim that processes concerned with iconic readout can modify the dichoptic masking function. More precisely, those experiments showed that the distinctions between words and nonwords, and between presentation to the left and right hemispheres were effectively and selectively realized at relatively long onset-to-onset intervals.

The above observations, taken together with the phenomenological reports cited in Experiments D1 and D2, suggest to us that the truncation of algoristic attention to the first of two iconic representations is a source of central masking above and beyond those summarized in Figure 10. In acknowledgement of this understanding, Figure 10 is altered to accommodate an iconic readout function. Figure 16 depicts iconic

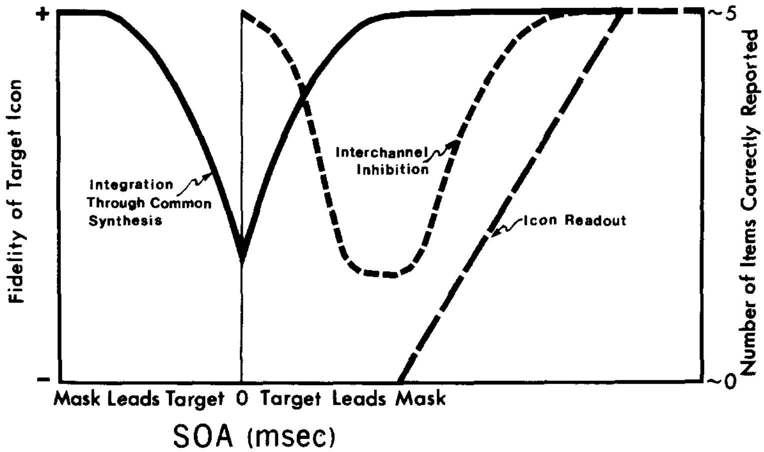

Fig. 16. A three-factor account of central masking

readout as a linear function of SOA, beginning, somewhat arbitrarily, at a point roughly coincident with the point of inflection of the interchannel inhibition function. It is supposed that the slope of this line reflects the rate or efficiency of readout from iconic memory: it is steeper for words than for nonwords and steeper for the left hemisphere than for the right.

If rate of translation of the iconic representation into a more permanent form does determine the slope of the readout line, then it might be asked: What parameters of stimulation, in addition to those investigated in the three preceding experiments, are relevant to the manifestation of this temporal constraint? An obvious candidate for such a variable is the number of letters in the target field; consequently, Experiment E4 asked observers to report target fields containing one, two, or three letters.

In addition, the present experiment asked: where in the masking curve would there arise an effect due to the amount of overlap of target and mask? All of the masking patterns used in the present series of experiments may be characterized as overlapping patterns, insofar as the area occupied by the pattern is the same as the area occupied by the target letters. There is, however, another sense in which a mask can overlap a target: the actual line segments that constitute the letters in the target field can be 'covered' by corresponding segments in the mask field. If our general interpretation is substantially correct, two masks, one in which there is a line-for-line overlap, and one in which there is not, ought to show differential masking effects in the integration and/ or transient/sustained interactions, but they ought not to differ in the domain of the replacement principle. The reasoning is that since both 'overlapping' and 'nonoverlapping' masks are viable visual occurrences, they should be equally successful at abrogating the attention of a central algorist to the first icon.

In sum, Experiment E4 collects together our previous observations through the manipulation of two variables. The first variable is the number of letters in the target field; according to the current theory, this variable would exert a selective influence on the masking function at relatively large SOAs where the function is determined primarily by temporal limitations on the algorist. The second variable is mask type, overlapping or nonoverlapping; on the current theory, this variable would exert a selective influence on the masking function at relatively small SOAs, where the character of the function is determined primarily by integration through common synthesis and/or interchannel inhibition.

Method. The masks and targets were prepared as follows. The overlapping mask, the upper mask shown in panel A of Fig. 17, was prepared and it provided the prototypic shape for the creation of block-letter unigrams, bigrams, and trigrams. Only consonants that could be mapped onto the prototypic shape were employed (C, F, G, H, J, L, P, S). Twenty-four cards were constructed for each number of targets such that each letter subtended 1.97° of vertical and 1.08° of horizontal visual angle. The thickness of the lines was $.16^{\circ}$ of visual angle. The unigrams were all in the center position, the bigram letters were always on the left and right (centered 1.79° to the side of the middle position), and the trigrams, of course, occupied all three positions. The second mask, whose contours overlapped the targets only at right angles is pictured along with the 'overlapping mask' in Fig. 17. The same three-member mask was used independent of the number of letters to be masked.

Eight Lake Forest College students served as observers. Each received 600 trials, 200 of which had one target letter, 200 of which had two target letters, and 200 of which had three target letters. Of the 200 trials at each number of target letters, 100 targets were followed by a mask whose contours precisely overlapped the contours of the letters, and the other 100 targets were followed by the mask that spatially overlapped the area of the target but not the particular letter contours. These 100 trials were further broken down into 10 trials at each of 10 SOAs (0, 10, 20, 30, 40, 50, 60, 80, 100, and 150 ms). Of these 10 trials at each SOA, the target was delivered to the right eye and the mask to the left on five trials, and vice versa on five trials.

Mask and number of targets were randomized within 100 blocks of six trials; SOA (in ascending and descending series) was counterbalanced in 20 blocks of 30 trials. Eye was balanced in two blocks of 300 trials, with half the observers beginning with targets presented to the left eye and half beginning with the right eye.

All cards were exposed for 10 ms at a luminance of 108 cd/m^2. A white point on a black field was used for fixation. Finally, all cards were presented on a Scientific Prototype three-channel tachistoscope (Model G) modified with polarizers for dichoptic viewing.

Results and Discussion. The data were summed over trials and eye and these sums were subjected to an SOA x Mask Type x Target Number x Observers ANOVA. All main effects and interactions were significant.

Onset asynchrony, averaged over the other variables, related in its characteristic J-shaped fashion to identifiability, and was the single largest source of variance, $F(9, 63) = 16.88, P < 0.01$. The main effect of Mask Type, $F(1, 7) = 53.06, P < 0.01$, revealed that the 'overlapping' mask impaired performance more than did the 'nonoverlapping' mask, 75% correct vs. 83% correct, respectively. The final main effect, number of targets, $F(2, 14) = 5.14, P < 0.05$, revealed that the percentages correct were equal for one- and two-letter targets (82%), but significantly lower for three-letter targets (72%).

The origins of the interactions, however, are most relevant to the issues at hand. Let us begin with the first-order interactions. In the Mask Type x SOA interaction, $F(9, 63) = 8.02, P < 0.01$, plotted in Figure 17a, the two masks show roughly equivalent amounts of masking at SOA = 0. The two curves then diverge to a maximal difference

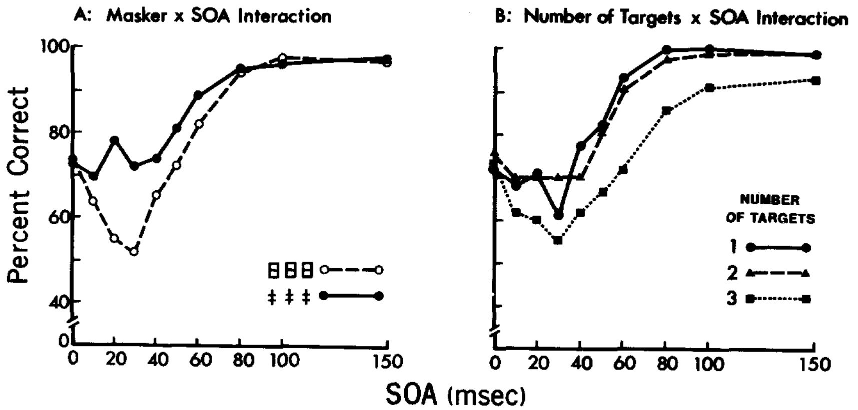

Fig. 17. Relation between target identifiability and SOA for dichoptic masking with (A) mask type as the curve parameter and (B) number of target letters as the curve parameter in Experiment E4

at SOAs of 20 and 30 ms, and then begin to converge as the functions ascend. In terms of the current account, the primary difference between the two masks is most evident in the range of onset-to-onset intervals that is influenced by interchannel inhibition.

The second first-order interaction, the SOA x Number of Targets interaction, $F(18, 126) = 2.81, P < 0.01$, is graphed in panel b of Figure 17. Here it is seen that targets with one and two letters are roughly the same over the entire range of SOAs; there is a slight, but consistent advantage of the one-letter targets at SOAs over 30 ms. Performance on the three-letter targets, however, is much poorer. Their identifiability is the same as the one- and two-letter targets for SOA = 0, but beyond that point, performance on the trigrams becomes markedly inferior. The maximal inferiority of the trigrams exists at 60 ms SOA, where observers report 18% more of the bigram letters and 21% more of the unigram letters. The effect of number of letters exists over an extended range of SOAs. Nevertheless, we can observe, in support of the hypotheses advanced earlier, that the slopes of hypothetical best-fit lines describing the ascending portions of the curves would be steeper for the one- and two-letter targets than for the three-letter targets. This interaction provides some support, albeit limited, for the existence of a temporally constrained 'readout' process.

The final two-way interaction, the Number of Targets x Mask type effect, $F(2, 14) = 4.38, P < 0.05$ found that the 'overlapping' mask caused more impairment than the nonoverlapping mask, but the amount of differential impairment varied as a function of number of targets. This differential impairment was 5.5%, 9.4%, and 6.9% for the one-, two-, and three-letter targets respectively.

Finally, the second-order interaction, $F(18, 126) = 1.99, P < 0.05$, is plotted in Figure 18. The source of this interaction is the upward trend at SOA = 20 in the one- and two-letter targets masked by the nonoverlapping mask. This trend, demonstrated by all eight observers, existed neither with the trigrams followed by the nonoverlapping mask, nor with any number of targets followed by the overlapping mask. What makes this observation intriguing is that it may reveal a new family of previously undiscovered masking functions — N-shaped functions (see Weisstein, 1971, for a demonstration of W-shaped functions). Functions of this shape could be, in principle, predicted by our

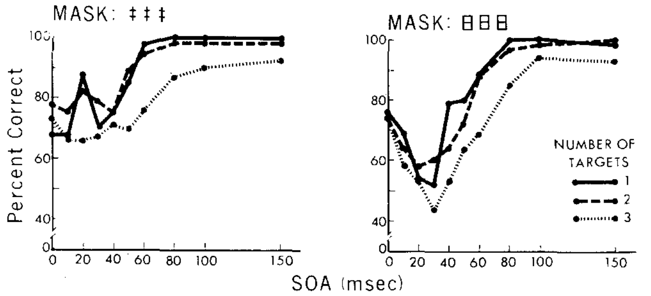

Fig. 18. Relation between target identifiability and SOA for dichoptic masking with two mask patterns and with number of target letters as the curve parameter in Experiment E4

theory and that of Breitmeyer and Ganz (1976). If we refer to Figure 16 and imagine a very small simple integrative component, and at the same time a robust transient/ sustained or interchannel inhibition component, we might expect a masking curve not unlike the two revealed in the left panel of Figure 18.

It is not at all clear why this particular mask should induce such an effect or why this effect is limited to the situation in which only one or two targets are presented. In the absence of any reasonable speculations about why these variables generated this peculiar curve, we shall simply take from the three-way interaction the idea that the masking curve may be even *more* malleable than had previously been assumed and that it can depart from its characteristic J-shape.

In summary, the results of Experiment E4, although at times complex and puzzling, seem to provide broad, tentative support for the three-factor account of central masking as presented in the current communication. First, we saw the three-way interaction providing evidence for the idea that two different types of masking, simple integration and transient inhibition of sustained channels, can alter the shape of the masking curve to the left of, and at, the nadir. Second the temporal locus of the difference between the two types of masks is coincident with the temporal locus of the differential effects of mask color and contrast (Experiments C1 and C2). Again, it is argued that differential effects in this region are owing to sustained/transient interactions. Finally, the shape of the ascending part of the masking curves differs as a function of the number of items to be reported. This difference is suggestive of the viability of the third source of central masking, namely, a constraint imposed by the after-coming mask on the duration of undivided algoristic attention to the target.

Summary of Experiments D1 to E4: The Algorist Function

Experiments D1 to E4 were mainly concerned with the proposition that a temporal limitation on undivided algoristic attention (or target icon readout) provides an upper limit on performance when target and mask are separated by a relatively large onset asynchrony. This limitation was proposed as a third source of central masking; the first and second – integration through common synthesis and interchannel inhibition – had been investigated in Experiments A1 to C2.

Intuitively, the principle of icon replacement implies the experience of two successive visual fields. It was demonstrated that at relatively long SOAs, observers can correctly report the temporal order of two visual objects (Experiment D1) and, moreover, will report the phenomenal experience of two distinct visual objects (Experiment D2).

However, if the onset-to-onset interval is too short, the observer will report seeing only one object (Experiment D2) and will be unable to make temporal order judgments above chance (Experiment D1). At least at some level of the nervous system, it makes sense to speak of two neural descriptions: one a description of the first of two successive visual fields and one a description of the second. It is notable that within the range of SOAs where observers report two distinct and temporally asynchronized events, strong masking effects are demonstrable. This observation relates to Haber and Standing's (1969) identification of a range of intervals over which observers report a 'clear' icon, but cannot identify its constituent elements. To the extent that icons are visible (cf. Turvey, 1978), the phenomenology of successive and dichoptically opposed visual fields stands squarely behind a two-icon interpretation.

To test the assumption that in the conditions yielding two successive icons, the constraint on the algorist vis-à-vis target identification is one of time, we sought vairables that would affect speed of recognition and thus the shape of the ascending part of the dichoptic masking function. This endeavor materialized in Experiments E1 to E4.

Experiment E1 compared the dichoptic masking of consonant-vowel-consonant (CVC) words and consonant triplets. It was reasoned that individual letters in a word would be identified with greater facility than individual letters in a consonant trigram. The letters of words and nonwords differed in their identifiability under masking, but the difference, as predicted, was limited to the ascending part of the dichoptic masking function.

An integration-alone theory of masking (Breitmeyer and Ganz, 1976), seems hard pressed to explain the word/nonword results. If one were to say, for example, that words simply are easier to read out of a composite data set that embodies information about a mask and, to a lesser extent, about a target, then one would expect to find an advantage of words over nonwords across the *entire* range of SOAs. However, such was not the case. Alternatively, an Integration theory might propose that spatial frequencies relevant to word recognition are different from those frequencies relevant to nonword recognition. This hypothesis could account for the observed results, but such speculation seems unjustified. In short, it is not immediately clear how an Integration theory of masking could account for the operation of a variable that is evident solely in the ascending part of the J-shaped central masking function.

In Experiments E2 and E3, attention was focused on laterality effects in masking. Differences between the hemispheres are generally considered to arise from processing or attentional differences; in terms of the current thesis, such differences should be apparent at large SOAs where the function reflects mainly temporal constraints on the algorist.

The viability of these suggestions was supported in both experiments. Experiments E2 and E3 revealed that target letters delivered to the left (language) hemisphere were more accurately identified than target letters delivered to the right hemisphere. The differences between the hemispheres, however, emerged only in the ascending part of the masking curves (see Moscovitch, Scullion, and Christie, 1976); the descending parts were virtually overlapping.

In addition, the hemisphere experiments revealed that the curves could be further split as a function of a word/nonword distinction that was evident in both hemispheres and, as a function of 'pronounceability,' that was evident in the right hemisphere alone.

Again, the effect of these variables within the hemispheres was limited to the ascending part of the dichoptic masking function.

In a further attempt to support the hypothesis that a process in addition to interchannel inhibition influences the ascending portion of the curve, Experiment E4 compared (among other things) the shapes of masking curves for targets containing one, two, or three letters. On the assumption that the replacement principle bears on readout rate, it was reasoned that 100% of the letters in a unigram should take less time to read out of an icon than 100% of the letters in a trigram. This notion found some support in the demonstration of maximal differential masking in the ascending masking function. This conclusion, however, must be tempered by the fact that the effect of number of target letters was observed over a very large range of SOAs and was simply larger in the predicted regions.

To conclude this summary of Experiments D1 to E4, a more general consideration of the algorist function will be given, and so will provide the necessary backdrop for the final experiments of the present communication, Experiments F1 to F4. As has been remarked more than once, there are two fundamental constraints on algoristic activity; in one, the algorist suffers from imprecise data and in the other, from insufficient time. An interpretation of visual masking in the language of algoristic constraints is closely cognate with theories of selective attention (see Broadbent, 1971, for an overview) on the one hand, and general theories of performance limitation (Garner, 1974; Norman and Bobrow, 1975), on the other. Indeed, in the present paper the replacement principle has been advanced as an attentional concept; attention is drawn from the leading to the lagging visual field. Other students of the phenomenon (e.g., Bachman and Allik, 1976) who have sought a broad characterization of visual masking in attentional terms can also be recognized.

If there is a switching of attention from the first to the second of two successive icons, then it may be supposed that it takes a finite time to switch, in the sense of changing the parameters of the selection system (c.f. Broadbent, 1971). In terms of the clerk-customer metaphor, the later-arriving customer must queue momentarily while the clerk disengages herself, as it were, from the earlier customer. 'Queuing' identifies a central effect of the leading field on the lagging field; a forward-operating influence that would not be revealed in the limiting case of two successive visual fields (because there would be always sufficient time to process the second), but might be revealed in the case of three successive visual fields (in which case there would be a limit on the time to process the second).

Furthermore, where masking arises from an attentional shift, it would not be expected that the neural record of the leading field be annihilated by the transfer of attention. On the contrary, the neural record or and, therefore, information on, the leading field, should persist. But how might this persisting record be revealed?

These ideas lead to a look at the situation in which *three* visual fields are presented to an observer in rapid succession. It has been suggested that the three-field situation might throw light on queuing; there is reason to believe that it might also throw light on the continued persistence of a masked field.

F. Three-Field Phenomena: Queuing for Algoristic Attention

Experiment F1

The point of departure for the final series of experiments is provided by an experiment by Turvey (1973, Experiment XVII). In this experiment, three displays were presented in rapid succession, the first and second to one eye, and the third to the other. The interval between the first and second was such that when presented as a pair, the second impaired the perception of the first. The interval between the second and the third was such that, when presented as a pair, the second evaded the masking action of the third. When the three were presented together at these same intervals, the perceptibility of the second decreased, while the perceptibility of the first increased. Stated bluntly, a previously masked target was substantially unmasked, that is, 'recovered', and a previously unmasked target was substantially masked. Let us replicate these observations before discussing them in the context of algoristic constraints.

Turvey's (1973) observations of the increased perceptibility of the first field and of the decreased perceptibility of the second field were based on reports of the phenomenal presence or absence of, and subjective quality of, the briefly exposed displays. The replication uses identification of variable targets as the dependent measure.

Method. The general paradigm is graphically portrayed in Figure 19. In condition 1, one target, T1, precedes the second target, T2, and ISI_1 is defined as the interval between offset of the first and the onset of the second. In Condition 2, a mask follows the target and ISI_2 is the interval elapsing between target offset and masker, M, onset. In Condition 3, the forward and backward masking situation of Condition 1 and 2, respectively, are combined, retaining the same mask and the same ISI values. Both targets were overlapping trigrams. The third member of the trio was a patterned mask. The trigrams and the mask were those described in Experiment A1. In all conditions, T1 was presented to the left eye; T2 and the mask were presented to the right eye.

The Scientific Prototype six-channel tachistoscope described in Experiment A1 was used to present the targets for 5 ms and the mask for 50 ms, each at 13.7 cd/m^2.

For each observer, the two intervals, ISI_1 and ISI_2, were determined in accordance with the following criteria. The interval between T1 and T2 was that interval at which the identification of T2 was close to perfect and the identification of T1 was minimal. The interval between T2 and the pattern mask was the minimal interval at which the identification of T2 was virtually unaffected by the after-coming pattern mask. The two intervals, ISI_1 and ISI_2 were estimated in Conditions 1 and 2, respectively. The procedure used was simply that of increasing the ISI gradually from zero in 2-ms steps until an interval was reached at which observers correctly identified four T2 consonant trigrams in succession. Once these intervals were determined, the experiment began. Five observers, all naive about tachistoscopic experimentation, received the same

Condition 1	T1	ISI_1	T2		
Condition 2			T2	ISI_2	M
Condition 3	T1	ISI_1	T2	ISI_2	M

Fig. 19. A schematic of the three-field paradigm

randomization of 90 trials, 30 each of the three conditions set out in Figure 19. Each trial was scored for the number of letters correctly reported.

Results. The preliminary testing yielded average values of 45 ms and 83 ms for ISI_1 and ISI_2 respectively. The results of the experiment proper are given in Table 2. Because the design was not factorial, two repeated-measures ANOVAs were performed. The first examined accuracy of T2 identification as a function of conditions. The analysis yielded a significant effect of conditions, $F(2, 8) = 20.3, P < 0.01$, that was attributed to the lowered T2 reportability evidenced in Condition 3. The second analysis compared the number of T1 letters reported with the number of T2 letters reported in Conditions 1 and 3. This analysis revealed that T2 letters were reported better than T1 letters, $F(1, 4) = 16.1, P < 0.05$; that the total number of letters reported (combined T1 and T2 scores) did not differ between Conditions 1 and 2, $F(1, 4) = 5.05, P < 0.10$; and that the interaction between target position, that is, T1 and T2, and conditions, was significant, $F(1, 4) = 43.9, P < 0.01$. The significant interaction taken together with inspection of Table 2 indicates that the number of T1 letters reported correctly increased from Condition 1 to Condition 3, while the number of T2 letters reported correctly decreased.

The identifiability of items in the three-field paradigm corresponds to their visual quality as described by Turvey (1973). Experiment F2 gives a second demonstration of the two phenomena, one which lends support to the claim that the phenomena are of central origin.

Experiment F2

An additional observation to be made from Experiment F1 is that the perceptual enhancement and the perceptual depression of the first and second fields, respectively, do not depend on these two fields sharing the same eye. In short, the *potential* for integration of the first two fields through within-net time-sharing is not a prerequisite for the enhancement and depression effects manifest in the three-field paradigm. Now it is asked whether the potential for within-net integration of the second and third fields is a prerequisite. To this purpose, Experiment F1 is replicated with the first and third fields presented to one eye and the second field presented to the other.

Method. Two observers (University of Connecticut graduate students) were tested in a design identical to that of Experiment F1, except that T1 and the mask were presented to the left eye and T2 was presented to the right. The T1 and T2 fields were the trigrams described above, and the luminance and duration values of T1, T2, and the

Table 2. Experiment F1: Percent correct identification as a function of condition with T1 presented to the left eye and T2 and M presented to the right eye

Condition	T1	T2
1	30.6	91.7
2	--	90.4
3	47.1	57.3

mask were the same as those used in Experiment F1. The values of ISI_1 and ISI_2 were estimated in the manner described in Experiment F1; for the one observer these values were 40 ms and 60 ms, for the other they were 50 ms and 80 ms.

Results and Discussion. The percent-correct identification averaged across the two observers for each condition is given in Table 3. Comparison of Tables 3 and 2 suggests that the two phenomena, enhancement of the first field (T1) and depression of the second (T2), are indifferent to the eye relation (monoptic or dichoptic) holding between any pair of fields. By implication, the sources of masking of relevance to those phenomena are the central sources defined above; more precisely, the enhancement and depression effects are not dependent, wholly or in part, on the potential for integration through within-net time-sharing.

We capture the essence of the last two experiments as follows: given three visual fields and interstimulus intervals (ISIs) such that when the first and second are presented dichoptically (monoptically) as a pair, the second impairs the perception of the first; and when the second and third are presented monoptically (dichoptically) as a pair, the second evades the masking action of the third; then, when all three are presented in succession, in the manner described and at these ISIs, the perceptibility of the first field is increased, while the perceptibility of the second field is decreased.

There is another three-field result, not uncommon to research in visual masking (e.g., Dember and Purcell, 1967; Long and Gribben, 1971; Robinson, 1966, 1968, 1971), whose essence may be captured in this manner: given three visual fields and ISIs such that when the first and second are presented binocularly (or monoptically) as a pair, the second impairs the perception of the first; and when the second and third are presented binocularly (or monoptically) as a pair, *the second is masked by the third*; then, when all three are presented in succession, at these ISIs, the perceptibility of the first field is increased. This latter three-field temporal arrangement and its results, will be described as 'less interesting,' in contrast to the three-field temporal arrangement identified in the immediately preceding paragraph, which we dub 'more interesting.' The rationale for drawing this contrast is expressed below.

Robinson (1966) reported an experiment in which three concentric disk flashes, differing in angular subtense, were presented binocularly (that is, both eyes received all three fields). The interval between the second and third flashes was 20 ms; at this temporal separation the third flash effectively masked the second flash in the absence of the first. Under the foregoing conditions of observation, the detectability of the first flash, when followed by the second, was significantly enhanced by the presence of the

Table 3. Experiment F2: Percent correct identification as a function of condition with T1 and M presented to the left eye and T2 presented to the right eye

Condition	T1	T2
1	13.3	97.2
2	–	83.9
3	48.3	51.1

third flash. However, a further experiment (Robinson, 1968) demonstrated that this particular enhancement effect did not occur if the third flash was dichoptically opposed to the second. In conjunction, the two experiments were taken as inferential support for the claim that the observed first-field enhancement was due to transretinal recurrent influences (cf. Robinson, 1971); the third flash laterally inhibited the second, thereby 'disinhibiting' the first.[12] In the terminology of the present paper, it can be said that the location of the second mask's (third flash's) influence on the first mask (second flash) was within the peripheral nets.

A further example of a 'less interesting' three-field arrangement and result (Turvey, 1973, Experiment IV) follows, an example that differs in significant ways from the one just described. The target field was presented to one eye and the first mask was presented shortly after to the other eye, giving dichoptic masking. When the first mask was followed by a second mask on the same eye, the target's perceptibility was virtually perfect. If, however, the second mask followed dichoptically the first mask at the same ISI, the target remained masked. In this three-field situation, therefore, the first mask affected the target through central sources of masking, while the second mask affected the first mask through within-net time-sharing. (Significantly it should be noted that the second mask, unlike the first, could not mask dichoptically the target field at any SOA; and that monoptically, the second and greater energy mask effectively masked the first, at the selected onset-asynchrony and did so in the absence of the target field.)

What makes these examples 'less interesting' is the order of explanation accommodating the target recovery effect: the second mask eliminated (or inhibited) data on the first mask in the peripheral nets, thus preventing the entry of first-mask data into the iconic synthesis and thereby removing the first mask as a competitor for algoristic attention.

The condemnation of the preceding examples as 'less interesting' is put into relief by considering the 'more interesting' cases of Experiments F1 and F2. We have been able to infer that for Condition 3 of those experiments, data on the second field were not prevented by the third field from gaining access to more central mechanisms and, therefore, that recovery of the first field related solely to central sources of masking, as they have been defined. In order for the first field to have increased in reportability, it was necessary that the second's influence upon it be reduced; this means that the third field had to mask the second effectively. Here is the problem: given that the third field followed at an interval in excess of the range of significant masking, by what means did the presence of the first field increase the third's masking capability and thus result in the increased perceptibility of the first? The reader will readily appreciate that

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[12] Some experiments have had difficulty in demonstrating the first-field enhancement effect in conditions similar to those of the Robinson (e.g., Schurman and Entesen, 1969; Barry and Dick, 1972). Moreover, where the effect has been demonstrated in Robinson-like conditions, the demonstration has tended to rely on the observer adopting relatively high criteria (cf. Kahneman, 1968) for response. In our view there are a variety of first-field enhancement effects; some are labile and rest on the use of phenomenal report, and some are robust and can be obtained with an identification criterion (e.g., Turvey, 1973, Experiment IV). Insofar as first-field enhancement can be produced in several distinctively different ways, the implication is that the effect is not a unique indicant of a special neural process. Hence our attempt to distinguish, albeit crudely, between 'less interesing' and 'more interesting' instances of the effect.

what we have dubbed as the 'more interesting' three-field arrangement requires an explanation of first-field recovery that is an order of complexity greater than that required by the 'less interesting' arrangement. Insofar as first-field enhancement is coupled to second-field depression, any explanation of the former must be, at the same time, an explanation of the latter and vice versa.

Currently, there are two hypotheses relating to the second-field depression that occurs in the 'more interesting' three-field arrangement. One of these hypotheses, that of queuing, was anticipated in the summary to Experiments D1 to E4 and it will be given a further and more detailed hearing below. The other hypothesis, summation, is due to Uttal (1969, 1971) and Walsh (1971). The summation hypothesis was proposed for the perceptual deterioration of a dot alphanumeric character interjected into the temporal 'hole' between two random dot masks that, at the intervals chosen, were proactively and retroactively impotent as individual masks (Uttal, 1969). In their discussion of this phenomenon, referred to as 'the character in the hole' (Utal, 1969), Uttal (1971) and Walsh (1971) converged on the conclusion that the 'noise' constituted by the leading mask and the 'noise' constituted by the lagging mask combined to yield a noisy background of sufficient strength to reduce the identifiability of the dot character. In reference to the character's insensitivity to the masks when they were presented individually, Walsh (1971) cautioned that '...discriminability is not equivalent to invulnerability' (p. 265).

Both integration through common synthesis and interchannel inhibition may be regarded as sources of noise, and according to the summation hypothesis, these central determinants of masking would assume responsibility for the second-field depression phenomenon. According to the queuing hypothesis, however, this responsibility is assumed by the replacement principle – more precisely, by a delay in replacement. The upshot of the queuing hypothesis is this: if the iconic representation of one visual field follows closely on the heels of the iconic representation of a previously presented visual field, the second arriving representation will have to wait temporarily for access to the algorist. In a two-field situation, this delay would have no consequence for second-field identification; however, if a third field followed the second, the second field might be 'pushed' into the masking range of the third. In the third experiment of the F series, the focus is on second-field depression primarily from the perspective of the queuing hypothesis.

Experiment F3

The queuing hypothesis does not deny the preemptory status of a lagging visual field in the domain of the replacement principle; it simply recognizes that preempting is not instantaneous. Experiment F3 is directed at the question of whether the interval for which the second field must wait is related to the duration of undivided attention given to the first field.

How might 'queuing time' be measured? Consider Figure 19. The claim is made that an appropriate measure is provided by the minimal addition to ISI_2 that restores the perceptibility of the second field (T_2) in Condition 3 to the level it enjoyed in Condition 2. This claim derives from the following considerations. The interval ISI_2 is that minimal interval at which T_2 evades masking by M. ISI_2 is interpreted as either the minimal time needed to process T_2 to the criterion level or the maximal interval over which M can impede the processing of T_2 to the criterion level (Turvey, 1973). At all events, when T_1 is added to the situation, part of the processing interval (that is, ISI_2) is devoured by the switching of attention from T_1 to T_2. For present purposes, as remarked above, attention is the application of resources, say, algorithms, to an object and the switching of algoristic attention is itself an algorithm that takes time to execute (cf. Moray, 1969). It is supposed that the time taken to switch attention is, metaphorically, a time-out from processing; no information is procured on either the leading or the lagging representation. Here then is the rationale for our measurement claim: if ISI_2 is the interval, in milliseconds, permitting the processing of T_2 to a criterion level, then in the presence of T_1 this interval is effectively reduced to (ISI_2 - t) milliseconds, where t is the switching or queuing time. Obviously, it follows that criterion performance on T_2 can be restored in Condition 3 through the raising of ISI_2 by t. The question asked by Experiment F3, therefore, materializes as follows: what is the minimal addition to ISI_2 needed to preserve the criterion identifiability of the second field, and does that minimal addition to ISI_2 change if we make additions to ISI_1?

A notable feature of the Experiments F1 and F2 was that the total number of letters reported correctly was constant for conditions T_1-T_2 and T_1-T_2-M, although the composition of the total differed between the two conditions. Thus, in Condition T_1-T_2, the second set of target letters was more accurately reported than the first, whereas in Condition T_1-T_2-M, the two sets were reported about equally. One implication of this feature of Experiments F1 and F2, is that whatever the reason for the recovery in T_1, the corresponding decrement in T_2 could have been due to limitations in the capacity of a memory system and/or to response interference. It is well known, for example, that the number of items that can be reported correctly from a brief, tachistoscopic display is on the order of four to five, although the actual reasons for this limitation are only partly understood (cf. Sperling, 1967; Coltheart, 1972; Turvey, 1978). In any event, it might be supposed that in Condition T_1-T_2-M of the two immediately preceding experiments, T_2 items were equally perceptible, but due to some limitation in storage or in response, or in both, they were less reportable than they were in Condition T_1-T_2.

In order to counter this explanation of the impairment in T_2 identification, the set of T_1 items was replaced in the present experiment by a patterned mask identical to the mask that followed T_2 in the previously described T_1-T_2-M arrangement. In short, a visual pattern that could be verbally coded with ease was replaced by one that could not. Preliminary observations revealed that the identification of T_2 was seriously impaired by a preceding and a succeeding mask presented jointly at ISIs, at which, independently, neither mask could effectively impede target identification. The implication is that the T_2 deficit observed in Experiments F1 and F2 was not due to a memory limitation on verbal report, and the experiment itself verifies this claim.

To summarize, Experiment F3 addresses two issues of relevance to the second-field depression that occurs in the 'more interesting' three-field arrangement: (1) the relation between ISI_1 and ISI_2 in determining second-field depression and (2) whether the second-field depression relates to short-term memory limitations.

Method. The design used in this experiment was essentially that depicted in Figure 19, with the exception that the first field is not a target, but a mask (M_1), identical in form to the third field which we now dub M_2. Conditions 1 and 2 were used only to estimate those values of ISI_1 and ISI_2 at which a variable target could be correctly identified on four consecutive trials. In Condition 3, seven values of ISI_1 were used – the ISI_1 value determined for a given subject in Condition 1 and six additions to that value (20, 50, 100, 150, 200, and 250 ms). The dependent measure was the increment in ISI_2 needed to restore identification of the target to criterion. Given a particular value of ISI_1, ISI_2 was gradually increased until the observer was able to identify a target correctly on four consecutive trials. A value of ISI_2 was estimated in this way for all seven ISI_1s. Each of seven observers received a different order of presentation of the ISI_1 values according to a Latin Square design.

The patterned mask used in Experiment F1 and F2 was used as both M_1 and M_2. All stimuli had luminances of 13.7 cd/m^2. Each mask was presented for 50 ms and the target was presented for 5 ms. The left eye received M_1; T and M_2 went to the right eye.

Results and Discussion. The additions to ISI_2 needed to restore second-field identification to criterion were averaged across observers. (The preliminary determination of ISI_1 and ISI_2 realized average values of 26.4 and 51.4 ms, respectively.) Figure 20 plots these additions to ISI_2 as a function of the additions to ISI_1. The graph reveals that the larger the addition to ISI_1, the smaller the increment to ISI_2 needed to reach criterion. The relationship, however, is not symmetrical; extending the interval prior to the target is not equivalent to extending the interval subsequent to the target. The graph also supports the claim that second-field depression occurs even when the number of items to be reported is well within the bounds of immediate memory limitations; second-field depression and short-term memory do not appear to be related.

On the queuing hypothesis, the result depicted by Figure 20 implies that the amount of time the representation of the second field must queue to access the algorist is an inverse function of the period of undivided attention allotted to the representation of the first field.

However, it must be said that while the present experiment was motivated by the queuing hypothesis, its outcome is not immune to a summation interpretation. One might claim that Figure 20 reveals the true extent of integration through common synthesis as it refers to the confluence of M_1 and T. In this case, the results of the

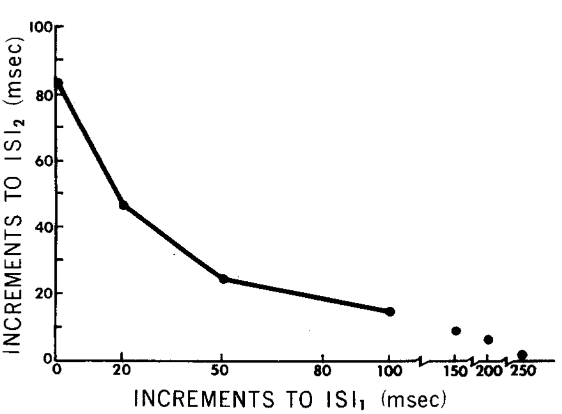

Fig. 20. Increments in ISI_2 needed to restore second-field identification to criterion as a function of increments in ISI_1 in Experiment F3

present experiment can be interpreted along these lines: because of integration through common synthesis M_1 degrades the iconic representation of T and retards the rate of processing of T in inverse proportions to SOA. This effect would pass unnoticed in the two-field situation, but would be manifestly plain in the three-field situation wherein the slowing of processing would augment the vulnerability of T to the after-coming M_2.

In the next and final experiment the distinction between summation and queuing as interpretations of second-field depression is sought. A summary of the present experiment emphasizes its principal lesson – namely, that the leading visual field has temporally extensive, central perceptual consequences for the lagging visual field that are not revealed in the two-field dichoptic forward masking paradigm.

Experiment F4

Within this paper, an appreciation of the central masking function and of the classes of variables that influence its character has been developed. In general, we have found variables that selectively influence regions of the function and we have taken such results as indices of different sources of masking. These results provide a conceptual backdrop for the question: where in the central J-shaped function does second-field depression arise and what is responsible for the effect, summation or queuing?

The dichoptic J-shaped function describes the identification of the first of a pair of visual fields as a function of the interval separating their onsets. The present experiment evaluates how this function is perturbed by a further visual field that precedes the pair by a constant amount of time. With the addition of a field that temporally prefaces the pair, the first field of the pair now becomes the second field of the trio and the expected perturbation of the function relating the identification of the first field of the pair to the interval between their onsets is therefore a time-titration on second-field depression.

The queuing hypothesis as developed here is specific on the locus of second-field depression. Queuing has meaning only in the context of rapidly successive icons, that is, where the constraint on algoristic activity is one of time. It follows, therefore, that on the queuing hypothesis, second-field depression should be selectively manifested in the ascending portion of the J-shaped function. The queuing hypothesis is also specific on how second-field depression is realized in the J-shaped function, precisely, as a displacement of the ascending portion of the function to the right of the nadir. If the first icon does induce a delay in algoristic attention to the second icon, then the readout of the second icon should begin at some point later than would be the case if there had been no immediately preceding icon. While queuing predicts a rightward displacement of the ascending phase of the J-shaped function, it does not predict a change in the slope of the ascending phase. Queuing merely delays iconic processing; it does not affect the rate of the processing that eventually ensues.

The summation hypothesis presents a more slippery case. The version of the hypothesis that Uttal (1969, 1971) and Walsh (1971) propose implies that second-field depression will be engendered as a nonselective overall depression of the J-shaped function. However, their version of summation is fairly nondescript with respect to sources of masking, and one intuits that Uttal and Walsh were considering all masking as occurring through energy-related or contour-related integration. A more judicious treatment of the summation hypothesis is provided in our conclusion of Experiment F3. In the three-field arrangement, the first field degrades the second and thereby slows the rate at which information is read from the icon of the second field. By this account, second-field depression occurs not because of a delay in the beginning of readout, as the queuing hypothesis would have it, but because of a slowdown in readout. Consequently, this refined version of the summation hypothesis predicts, as does the queuing hypothesis, that second-field depression is localized in the ascending phase of the J-shaped function, but that contrary to the queuing hypothesis, it should be manifest as a slope change. In the absence of any riders to this refined version of the summation hypothesis, it does not predict a rightward displacement of the ascending phase of the J-shaped function.

Method. Variants on two basic conditions, T1-T2 and M-T1-T2, constituted the design of Experiment F4. In the T1-T2 conditions, the word and nonword trigrams described in Experiment F1 were presented dichoptically at various SOAs (0, 20, 40, 60, 80, 100, 120, 150, 200, and 250 ms). Observers were asked to report as many of the six letters as they could (cf. Experiment B1). The arrangement M-T1-T2 was identical to the arrangement T1-T2, with the exception that a patterned mask preceded T1 at an ISI of 50 ms.

Six arrangements of targets, masks, and eyes were needed in all: 1) to balance out effects due to eye dominance and 2) to permit evaluation of the within-net effects of the patterned mask on the target (either T1 or T2) that happened to fall on that eye. These six conditions were as follows (the subscript r (right) and ℓ (left) referring to the eye to which that display was delivered):

$T1_\ell$-$T2_r$; $T1_r$-$T2_\ell$; M_ℓ-$T1_\ell$-$T2_r$; M_ℓ-$T1_r$-$T2_\ell$; M_r-$T1_\ell$-$T2_r$; and M_r-$T1_r$-$T2_\ell$.

Note that the two sets of targets were always presented dichoptically and, therefore, could not interact through within-network time sharing.

The displays were presented on the six-channel tachistoscope at 34.3 cd/m^2; the mask was of 50-ms duration and the targets are of 10-ms duration. Six observers (Yale University undergraduates) were required to balance the six conditions completely. The design was completely within-observers, each observer receiving 10 trials (five to each eye) at each of the 10 SOAs, in each of the six conditions.

Results and Discussion. The number of target letters correctly reported was calculated for T1 (as a measure of backward masking) and T2 (as a measure of forward masking). These numbers were then summed over trials and eyes. First consideration should be given the forward masking results, that is, performances on T2. While these results were relatively complex, owing to interactions of monoptic and dichoptic forward masking effects (depending on eye arrangement), they offered no surprises. We have, therefore, not presented these results graphically; a verbal description should suffice. The T1-T2 condition showed perfromance on T2 to be in excellent concert with those reported in Experiment B1 under virtually identical circumstances – the forward masking reaching asymptote at about 40 ms. Performance on T2 in the M-T1-T2 situation showed monoptic effects that, predictably, altered the character of the purely central effects observed in the T1-T2 condition. When the mask preceded T2 on the same eye, the forward masking extended to 80 ms, where 93% of the T2 targets were correctly identified. When the mask preceded T2 on the opposite eye, performance reached 94% at 20 ms. Performance in this latter case was, in fact, superior to the T1-T2 situation and this is attributed to intra-net masking of T1 by the mask and a consequent reduction in the visual viability of T1 in its role as a dichoptic forward masker of T2. When the effects of intra-net interactions are averaged out, masking, as revealed by performance on T2, existed over a substantially greater range of onset-onset intervals in the M-T1-T2 arrangement, than in the T1-T2 arrangement.

Backward masking (measured by performance on T1) in the T1-T2 situation yielded the familiar J-shaped relation between T1 identifiability and SOA. That curve is presented together with those observed in the two M-T1-T2 conditions in Figure 21.

Ignoring the T1-T2 curve for a moment, the two curves for the M-T1-T2 arrangement show the peripheral or within-net influence of the mask extending to about 80 ms. In the *M-T1*-T2 condition (with the underlined displays being those that were delivered to the same eye), performance is very poor at brief onset-onset intervals, but this intranet effect disappears at 80 ms where the *M-T1*-T2 function joins the *M*-T1-*T2* function. This latter function is essentially U-shaped and therefore shows reduced masking at relatively brief onset to onset times. It is supposed that this reduced masking is an instance of recovery of target in the 'less interesting' sense (cf. the discussion of Experiment F2). The patterned mask, presented to the same eye as T2, probably exerts a peripheral effect on T2 and thereby reduces the latter's potency as a dichoptic mask.

Keeping the T1-T2 results in abeyance, consider the M-T1-T2 curves in the context of Experiment A1 (Fig. 2). This is done to rationalize the averaging procedure described below. Such a consideration suggests that the present curves represent a central masking function with overlaid peripheral effects. If the results of Experiment A1 can be said to index the general relationship between central masking with and without peripheral effects, then Figure 2 implies that the average of the peripheral curves approximates the central curves. It is reasonable to assume, therefore, that an approximation to the 'pure central effects' of the M-T1-T2 situation in the present experiment can be had by averaging the two peripheral/central curves (*M-T1*-T2 and *M*-T1-*T2*). (Direct measurement of such 'pure' effects would require *trichoptic* presentations). Such averages were computed and are presented together with performance on T1 in the T1-T2 condition in Figure 22.

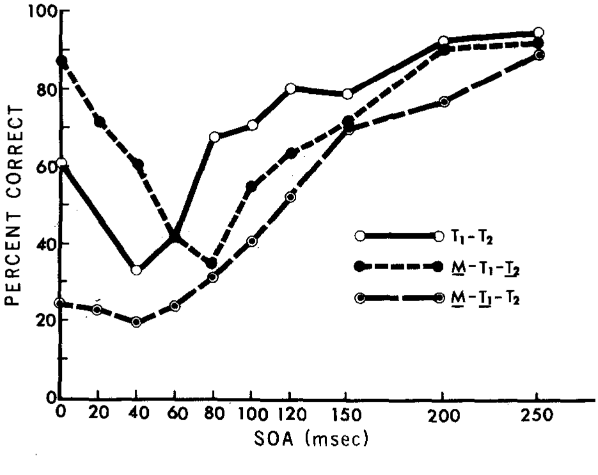

Fig. 21. Percentage of T1 letters correctly identified as a function of SOA between T1 and T2 for the three conditions of Experiment F4

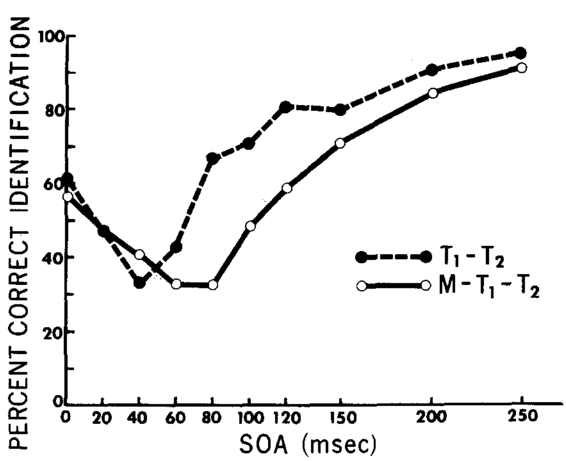

Fig. 22. Percentage of T1 letters correctly identified in Experiment F4 as a function of SOA between T1 and T2 with the two experimental conditions averaged

Consider now the consequences of the present experiment for the two hypotheses about second-field depression. First, the prediction common to the queuing and refined summation hypotheses is verified, that is, the locus of second-field depression is the ascending phase of the J-shaped masking function. Second, the queuing hypothesis predicts that prefacing T1-T2 by M should shift the ascending phase laterally to the right of the nadir. Inspection of Figure 22 reveals that when preceded by M, the rise in T1 identification is displaced about 40 ms to the right of the rise in T1 identification that occurs in the absence of M. An ANOVA showed that this interaction was significant, $F(9, 45) = 4.877, P < 0.001$. (In addition, both main effects, SOA and Conditions, were significant: $F(9, 45) = 31.91, P < 0.001$ and $F(1, 5) = 9.48, P < 0.05$, respectively). Third, the refined summation hypothesis predicts that the rate of increase in T1 identification will be slower when T1 is preceded by M. Inspection of Figure 22 suggests that this is not the case; the ascending phases are sloped equivalently for T1-T2 and M-T1-T2. All things considered, we may conclude that it is the queuing hypothesis that is favored by the outcome of Experiment F4.

Summary of Experiments F1 to F4: A Dilemma for the Theory

This last series of experiments examined the perceptual consequences of three temporally proximate and overlapping visual fields presented briefly to a stationary observer. The temporal arrangement of the three fields was constrained in the following way: 1) individually, neither the first nor the third of the three fields could significantly impair the identifiability of the second field. 2) the second field, individually, could significantly impair the identifiability of the first field. Constrained in this fashion, the three-field arrangement yielded the following two phenomena: an enhancement in the identifiability of the first field and a depression in the identifiability of the second field.

The two phenomena are of central origin (Experiments F1 and F2) and apparently unrelated to short-term memory limitations (Experiment F3). Further, second-field depression was shown to decrease nonlinearly with the interval by which the first field preceded the second (Experiment F3); to be localized to the ascending phase of the dichoptic J-shaped backward masking function (Experiment F4); and to be manifested as a rightward displacement of the ascending phase of the J-shaped function (Experiment F4).

In characterizing the replacement principle as an attentional concept (see Summary of Experiments D1 to E4), it was conjectured that a leading visual field should have effects on the perception of a lagging visual field that would not be revealed in the two-field situation. Precisely, in the domain of the replacement principle, the leading field should delay the lagging field's access to algoristic attention. On the basis of Experiment F4, the three-field phenomenon of second-field depression was acknowledged as evidence for such a delay, that is, as evidence for queuing. But second-field depression is coupled to first-field enhancement and the question is now whether or not the queuing hypothesis can account for *both* phenomena. A perfunctory analysis reveals that it fails to do so.

The dilemma, quite simply, is this: insofar as first-field enhancement and second-field depression are coupled and localized in the domain of the replacement principle, there is no logical way in which the first field can be allotted additional processing time – the necessary condition according to our theory, for improved performance on the first field in the domain of the replacement principle. As was remarked at the outset of the present paper and as the data of the reported experiments substantiate, the rule governing algoristic behavior when faced with successive icons is that lagging representations take priority. Thus, the second field preempts the first and the third field preempts the second. It has been argued that the first field delays the processing of the second, thereby reducing the effective interval between the second field and the third, and thereby accounting for second-field depression. With the advent of the third-field icon, algoristic attention switches to that icon, the later-arriving icon, and not to the first-field icon. In the absence of a mechanism by which algoristic attention can be returned to the icon of the first field, the current account of second-field depression fails as an account of first-field enhancement.

There is, in all probability, a resolution to this dilemma – perhaps, within the context of our own theory. A resolution has so far evaded us, and we seek solace in the intuition that the 'more interesting' three-field arrangement may require explanatory concepts outside the current scope of theories of two-field arrangements. More fundamentally, we intuit that the three-field theory may prove to be considerably more complex than two-field theory. That would not be surprising since two-field theory is the limiting case of a more general theory – that of the perceptual consequences of n successive visual fields (Turvey, 1978).

We shall forgo any lengthy concluding discussion on the data themselves, as the summary sections following each set of experiments, when taken together, serve that purpose. Let us conclude with these remarks: The model presented at the outset has received ample support from the two-field experiments that we have reported; the model's limitations, however, have been revealed by the outcome of the three-field experiments and it remains to be seen what kind of model accounts for these results.

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