INTERSENSORY INTEGRATION OF INFORMATION

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by

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A Thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science

Department of Psychology
Memorial University of Newfoundland
August, 1976

St. John's , Newfoundland

Abstract

The presentation of identical information to two sensory modalities improves a respondent's performance over his unisensory performance. Prevalent models of stimulus processing treat this performance facilitation as resulting from the improvement of primary channel (sense) function by a modification of primary channel operation caused by the input to the auxilary channel. It is argued here that the second channel does not modify the first, but that a merging of information occurs. A model built on this assumption is presented. Two choice reaction time experiments are reported in which both auditory and visual presentation of information is given to subjects. The visual information is critical to the choice, but it is found that the auditory stimuli alter the subject's response time in accordance with the informational content of the auditory stimuli. This is taken to indicate that the subjects analyzed the information content of both stimuli, and is used in support of the new model which proposes an information merger.

Acknowledgements

During my residence at Memorial I have undergone three major crises. I would like to extend my sincere gratitude to those people most helpful during those periods; this opportunity seems the most appropriate, since their efforts were made towards the end of a completed Master's Thesis.

First, I would like to thank Dick Taylor who sponsored me as a potential graduate student, and fought unremittingly for my acceptance into the graduate programme and for my financial support. I would also like to thank him for the time and money he invested in me during my first year of study. At the time of my application to Memorial I was destitute, without a place to go. Dick helped me back to my feet and rekindled my interests in Psychology.

Second, I would like to thank Ted Rowe and Graham Skanes who counseled me when I became an academic orphan. Both interceded in my behalf, enabling me to remain a graduate student, and were able to find a new supervisor for me.

Third, I would like to especially thank Cathy Penney for agreeing to supervise a rather scattered graduate student. She knew full well that I was interested in a topic outside her own specialization; yet she accepted the task of learning a new area in compound with the obviously tortuous problems of overseeing the completion of a Master's Thesis.

Beyond these singular acts of aid, which should be all a person could want, I find many more incredibly helpful people whose generosity allowed the completion of this thesis in one way or another. Gordon

Barnes donated many hours to find me Teaching Assistantships, to right my problems with payroll, and to generally clear up any problem I would encounter. I do not think I should give him a personal citation however, he did not do all this for me; Gordon is not the person who only helps those he likes, Gordon helps everyone who asks (and some who don't). I would like to thank Gordon as a graduate student, not as Terry Kenney.

As members of my Thesis Committee, Brian Craske and Mike Sherrick laboured many hours reading what must have become an arduously long and redundant manuscript. Their patient concern and conscientious criticism pointed out many ways to better communicate the concepts (often only dimly realised) I wanted to state.

A person who should not be missed when a graduate student dispenses gratitude is Fred Aldrich. As Dean of the School of Graduate Studies, he has long championed the graduate students' cause when other members of the academic community have forgotten these lowly constituents. Dean Aldrich works incredibly hard to find all students some form of financial support; I would like to thank him for the personal attention he gave me. I am most grateful for the University Fellowship I have received for the duration of my stay at Memorial.

Lastly, I would like to thank Frank Kenny who was kind enough to pay more than half the rent and remain a friend, and Denise Brennan who made the office I shared with her an enjoyable place to be.

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A person's performance in a detection task is improved when stimulation is given to both auditory and visual modalities compared to when stimulation is given to either modality alone (Buckner and McGrath, 1961; Morrell, 1968a; Todd, 1912). This does not seem surprising: if the subject's task is to detect stimulation, the probabilty of detecting one of two stimuli should be greater than the probability of detecting one stimulus alone (Brown and Hopkins, 1967; Raab, 1962). The underlying process through which this probability increase occurs, however, is not readily apparent.

The primary intent of this thesis is threefold: 1) to review experimentation concerned with tasks reflecting the interaction between auditory and visual processing; 2) to review the existing models of stimulus processing developed to account for performance facilitation with bisensory stimulation; and 3) to propose a new processing model to account for this facilitation. Two experiments will be reported which test the new model. The focus of this thesis will be on how stimuli supplied to different sensory modalities might interact so that stimulus information is unified and performance facilitated.

Intersensory arousal.

Certainly an increase in bisensory detection probability implies an interaction between the processes involved in visual and auditory stimulus detection; and, since the auditory and optic nerves are quite separate, any interlocution between auditory and visual systems must be assumed to occur centrally. A simple method of accounting for the increase in detection probabilty is to propose that the onset of any stimulus results in an arousal response within some central mechanism involved in general stimulus detection; hence, the occurrence of two stimuli results in a greater amount of arousal, facilitating the detection of stimulation. However, an experiment by Brown and Hopkins (1967) shows that the effect of bisensory stimulation is more subtle than would first appear.

Brown and Hopkins required their subjects to detect the presence of a 1000 hz tone embedded in a white noise background. The detection probability of the auditory task was adjusted to vary between .2 and .8 (in steps of .1) by altering the intensity of the tone against the constant-intensity background. The visual task was made equivalent to the auditory task by displaying the auditory stimulus trace on an oscilloscope. Visual detection probabilities were adjusted in the same way, to the same values, as were the auditory probabilities. The bisensory task used auditory-visual stimulus pairs matched for detection probability. Brown and Hopkins found the detection probabilities of the auditory-visual pairs higher than the detection probability of either unisensory stimulus alone.

Brown and Hopkins' experimental task required a functional interaction between the detection of a sinusoidal tone and the detection of a sinusoidal line if the auditory-visual detection probability was to exhibit enhancement. Since the sinusoidal targets were embedded in random noise, the increment in total systemic arousal caused by the inclusion of the target may be assumed to have been minimal; the actual task requirement was to abstract the sinusoid from the total stimulation. It was the feature of sinusoidality which was abstracted from the total stimulation in each modality and detected, it was not an arousal increment.

The notion that performance facilitation in bisensory tasks can be attributed to general arousal effects does not seem viable. Brown and Hopkins' data suggest the stimulus feature of sinusoidality was detected and combined between modalities to produce performance facilitation.

Response equivalence.

One way in which stimulus features might be combined is if they give rise to the same response. For example, Hilgard (1933) recorded eye-blinks following the presentation of either a light or a tone. When he presented the stimuli in progressively closer temporal succession, Hilgard found the two responses merged into a single blink of greater magnitude than blinks to either stimulus alone. The point of maximal summation was when the light preceded the tone by 40 msec. In a similar experiment, Hershenson (1962) required his subjects to press a button as soon as they detected the occurrence of either a light or a tone. From a point of simultaneous presentation the stimuli were progressively separated in time. Hershenson found bisensory facilitation of response time (RT) to first increase and then decrease as the light preceded the tone by greater periods. The point of maximal RT facilitation was when the light preceded the tone by 40 msec, precisely the temporal succession found by Hilgard to maximally facilitate eye-blinks. The responses of subjects to bisensory stimulation seem to be optimized when the responses to both stimuli are equated and the stimuli bear a certain temporal relationship to one another. This operational explanation is in essence similar to a theory developed by Sperry (1952) which states:

> Perceptions and ideas are found, upon analysis, to have their factual significance and meaning in terms ultimately of overt operation. Their meaning derives from the potential effect, that is, the difference they make or may make in behavior (p. 300).

The above quotation implies that, as shown by the experiments of Hilgard (1933) and Hershenson (1962), when the responses to two different stimuli are identical, the stimuli are behaviorally identical in meaning to the respondent; hence exposure to both stimuli gives the respondent two indices of the same conclusion.

When the condition of response equivalence is met, the invocation of neural summation would explain both faster and more intense responses. Neural summation refers to the temporal or spatial summation of nerve impulses at some reception point. If the reception point were considered to be some neuron or group of neurons controlling the evocation of a certain motor response, and if some threshold must be exceeded before the response could be initiated, a faster response could certainly be accounted for in cases where two inputs yield one response (eg. Hershenson's experiment) and more intense responses in cases where two inputs yield two responses (eg. Hilgard's experiment). Neural summation will be referred to henceforth as information summation inasmuch as the crucial characteristic of neural impulses (in the context of this thesis) is that the impulses carry information about the stimulus.

Another way stimuli might interact between modalities is also evident in the above discussion. Both Hilgard (1933) and Hershenson (1962) found the temporal relationship between the two stimuli was critical to response facilitation. Moreover, in both experiments maximal response enhancement was found when the visual stimulus preceded the auditory stimulus by 40 msec. Although these results support the contention that response equivalence determines stimulus interaction, they also bring into question the extent to which the stimulus sequence and SOA (stimulus onset asynchrony) influence performance. Since RT to a simple visual stimulus is generally greater than RT to a simple auditory stimulus by about 40 msec (Woodworth and Schlosberg, 1954) and evoked potentials to visual and auditory stimuli follow the same temporal order (Morrell, 1967), it might be argued that stimulus interaction between modalities is governed by the temporal sequence of the stimuli, as well as the condition of response equivalence. Thus, the results of Hilgard and Hershenson might be taken to support an hypothesis which predicts maximal response facilitation when the central arrival times of two indices of the same response coincide; that is, a spatial and temporal summation hypothesis. In terms of stimulus interaction, this hypothesis would mean that between modality interactions are determined by temporal coincidence of neural impulses at a certain site, an idea proposed by Milner (1974).

The Statistical Facilitation model.

Raab (1962) proposed a model of stimulus processing, the Statistical Facilitation model, which uses the interaction of two RT probability distributions to explain the response facilitation reported by Hershenson (1962). Raab pointed out how RTs, as used for descriptive purposes, are actually the mean RT of a distribution of obtained RTs. As such, the RTs Hershenson reported for auditory (RT_A) and visual (RT_V) trials represent two underlying probability distributions which provide the single RT for bisensory trials (RT_{AV}); the observed RT_{AV} is simply the faster RT between the two unisensory distributions.

Raab's explanation of Hershenson's data rests on an analysis of the SOA effect on RT_{AV}. All bisensory trials in Hershenson's experiment began with the onset of the visual stimulus, the onset of the auditory stimulus was either simultaneous with or delayed 5 to 85 msec after the onset of the visual stimulus. The bisensory RTs were compared to the unisensory RTs to determine the amount of facilitation. It was found that the amount of facilitation was symmetrically distributed about a maximum at a SOA of 40 msec. Raab argues this finding is best interpreted as the result of changing degrees of overlap between the two unisensory RT distributions: 1) when the stimulus onsets are simultaneous (at SOA = 0) there is no distribution overlap and RT_{AV} is determined by the faster RT_A distribution; 2) as the SOA approaches 40 msec the leading (faster) tail of the RT_V distribution begins to overlap the trailing (slower) tail of the RT_A distribution and some of the slower RT_A members are replaced in the RT_{AV} distribution by faster RT_V members; 3) when the SOA is equal to 40 msec the two unisensory distributions exactly overlap and the faster RT from either distribution will be the RT_{AV} sample; and 4) as the SOA increases beyond 40 msec the RT_V distribution dominates the membership of the RT_{AV} distribution to a greater degree until no overlap exists and the RT_V distribution is the sole determinant of the RT_{AV} distribution. This argument is depicted graphically in Figure 1.

Raab's model is called the Statistical Facilitation model because the RT facilitation seen when the SOA is 40 msec is considered to result from the increased probability of drawing the RT_{AV} sample from the leading portion of one or the other of the unisensory distributions. The Statistical Facilitation model differs from response equivalence notions (eg. Sperry, 1952) primarily in the postulation of SOA effects on the magnitude of facilitation since the unisensensory distributions are required to refer to the same response.

The SOA, however, may be the more potent consideration. For example, when a firecracker is ignited we tend to combine the flash of light and crash of sound together under the interactive concept "explosion"; on the other hand, when the visual and auditory stimuli are separated in time, as during an electrical storm, we tend to parse the two stimuli under the discrete concepts "thunder" and "lightning." Either the recruitment of a unitary response to two stimuli is dependent on a temporal relationship close to simultaneity, or the temporal attributes of the stimuli are the basic parameters defining bisensory interaction, or both.

The failure of response equivalence.

The facilitation of RT to one stimulus by the simultaneous presentation of a second stimulus in a second modality without

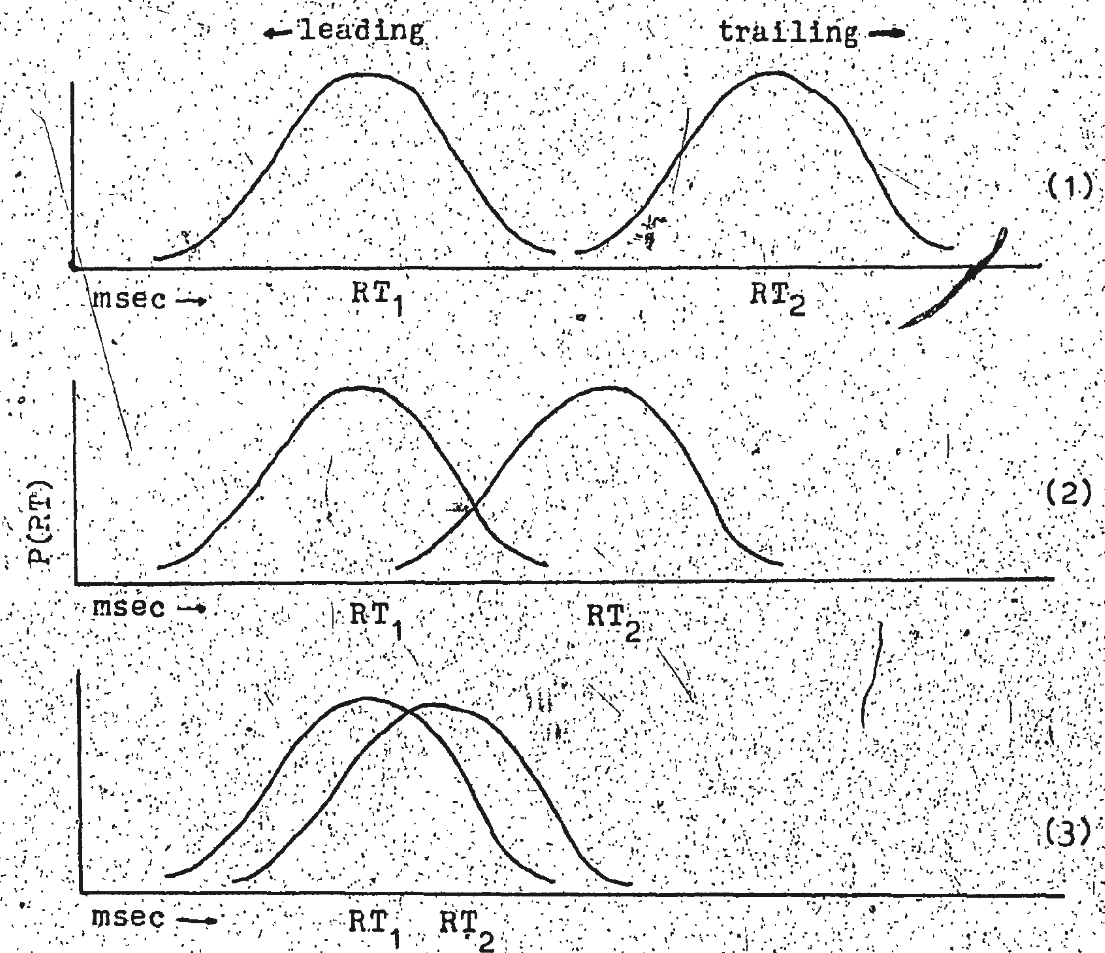

Figure 1

(1) When no distribution overlap exists, all bisensory RTs are determined by the leading distribution.

(2) As the trailing distribution begins to overlap the leading distribution, some of the faster members of the leading tail of the RT_2 distribution replace some of the slower members of the leading distribution in the bisensory sample.

(3) As the degree of overlap increases, more slow RT_1 distribution members are replaced in the bisensory sample.

the condition of response equivalence was demonstrated by Todd (1912). Todd used three stimuli, a flash of light, the sound of a solenoid closing, and a weak shock to the fingertip, presented singly or in simultaneously presented combinations of two and three. Todd found bisensory RT to equal the lowest unisensory RT the subject had made to one of the two stimulus components. This is the same finding Hershenson (1962) reported at a SOA of zero. However, whereas Hershenson had instructed his subjects to respond to either stimulus, Todd had his subjects respond to only one of the two or three elements of a stimulus combination (eg. the light). Hence, in Todd's experiment the stimuli did not give rise to the same response; yet Todd found the combination of auditory and visual stimuli to evoke the same RT as did the auditory stimulus alone, regardless of to which stimulus the subject was instructed to respond. Moreover, Todd's data show RTs to the three-stimulus combinations were less than bisensory RTs, a result more appropriate to an arousal interpretation than one of response equivalence. Clearly, Todd's study does not support the proposition that response equivalence is necessary to response facilitation.

Response facilitation arguments cannot be rejected on the basis of Todd's experiment. Unfortunately, Todd did not check to ensure that his subjects were in fact selectively responding to only one stimulus, as instructed. Without a manipulation check, the subjects may have simply responded to the first stimulus they detected, in which case Todd's results are objectively identical to Hershenson's (1962). If Todd had included catch trials (trials when only extraneous stimuli are presented), and if his subjects were able to successfully refrain from responding in the absence of the critical stimulus, a conclusion might be reached that the subjects had been selectively responding. More recently a number of experimenters (eg. Bernstein, 1970; Bernstein, Clark, and Edelstein, 1969; Bernstein, Rose, and Ashe, 1970; Morrell, 1968a, 1968b) have shown that subjects can indeed respond selectively to the critical stimulus and still exhibit a bisensory performance facilitation in a detection task. Response equivalence cannot be considered a prerequisite of bisensory response facilitation.

The finding that a task-irrelevant stimulus can serve to facilitate the response to a critical stimulus creates a problem in studying stimulus interactions: in particular, how does one stimulus modify the processing of a second stimulus seemingly unrelated to the first? Perhaps the answer lies in the process of stimulus identification. Logically, before a stimulus can be identified it must be noticed -- that is, the observer must be aware that "something is happening" before he can identify what the stimulus is. An increase in the number and/or intensity of the events "happening" might serve to hasten a stimulation-detection stage of processing without affecting the identification stage. This two-stage construct would describe the conditions of bisensory performance facilitation better than a strict arousal interpretation (see above) and still be in line with the inverse relationship found between stimulus intensity and unisensory RT (Woodworth and Schlosberg, 1954).

The Energy Integration model.

Bernstein (1970; Bernstein et al., 1969, 1970; Bernstein Chu, Briggs, and Schurman, 1973) argued for a two-channel processing model in which one channel integrates the total of all stimulus intensities impinging on all sensory organs within some unit of time, and the other channel operates selectively to identify the critical stimulus. This model thus proposes the separation of intensive and qualitative components of all stimuli such that only the intensive components of temporally proximal stimuli are integrated. Bernstein called this model of stimulus processing the Energy Integration model.

The Energy Integration model was developed to account for the effect of a second, task-irrelevant stimulus on RT to the critical stimulus. Bernstein et al. (1970) studied the effect of an irrelevant auditory stimulus on visual RT by manipulating (1) the SOA so that either stimulus might appear first in the sequence and (2) the intensity of both stimuli. They found the difference between RT_{AV} and RT_V (dRT) was normally distributed about a maximum value found when the stimuli were presented simultaneously. The measure of response facilitation, dRT, was significant within the SOA range of 40 msec before or after simultaneity. Perhaps more important was the finding of a significant interaction between stimulus intensities: dRT was directly related to the intensity of the auditory (irrelevant) stimulus and inversely related to the intensity of the visual (critical) stimulus. (It is important here to add that RT_V decreased with increasing visual stimulus intensity and that all dRT values were with respect to the RT_V value found for the intensity used in the bisensory trials.) Since the auditory stimulus was more facilitative when presented at the higher intensity and most facilitative when the visual stimulus was presented at the lower intensity, intensity summation seems to be directed towards the attainment of some threshold value; which, when reached, either initiates the response or allows the quality channel to control responding.

These results were elaborated on by Bernstein et al. (1973). In this study both critical-irrelevant stimulus pairings were tested to avoid the possibility that the results of Bernstein et al. (1970) were due to a peculiarity of the visual-critical and auditory-irrelevant pairing. Again, the intensities of both stimuli were manipulated between high and low, but only zero SOA was used and the delay between the pretrial warning signal and the presentation of the critical-irrelevant stimulus pair (or the irrelevant stimulus alone, on a catch trial) was varied between a short (.5 sec) and a long (5.5 sec) delay. The interaction between intensity and stimulus designation (critical or irrelevant) was again significant, regardless of which pairing was used, and the pretrial delay (the foreperiod duration) was found to significantly alter obtained dRT, the longer delay resulting in greater RTs. Catch trials were found to yield responses (false alarms) at a rate which was dependent on an interaction between the irrelevant stimulus intensity and the foreperiod duration: a false alarm was more likely to occur when the irrelevant stimulus was at the high intensity and the foreperiod delay was short.

Bernstein et al. (1973) developed a two-process explanation of these results. The effect of foreperiod delay length on dRT was attributed to response preparation effects which Bernstein (1970) described as deriving from conditions of temporal uncertainty:

> ...the irrelevant stimulus operates as a supplemental warning signal. As a result it will be most efficacious, and the amount of facilitation the greatest, when the subject is most poorly prepared to respond (p. 30).

Thus Bernstein argued that with long delays the subject uses the irrelevant stimulus to increase his readiness to respond, perhaps by adjusting his detection threshold (eg. Howarth and Treisman, 1958; M. Treisman, 1964). The response preparation effect would then be expected to be manifest in a greater dRT following a long foreperiod delay, which was indeed the case.

To account for the effects of stimulus intensity on dRT

Bernstein et al. (1973) invoked the Energy Integration model. When the critical stimulus was presented at the higher intensity the irrelevant stimulus added propotionately less energy to the system than when the critical stimulus was presented at the lower intensity.

The false alarm rate (FAR) data were more difficult to account for. The increase in FAR accompanying the increase in irrelevant stimulus intensity clearly follows from the Energy Integration model. The increased intensity of the irrelevant stimulus allows the evocation criterion to be reached in the absence of the critical stimulus, resulting in a false alarm. However, the response preparation hypothesis cannot account for a lower FAR when the foreperiod delay is longer. From Bernstein's (1970) description of the response preparation hypothesis, a longer foreperiod duration would be expected to result in greater temporal uncertainty. When temporal uncertainty is maximized, an artificial increase in response readiness caused by the arrival of the irrelevant stimulus should maximize the probability of a false alarm.

It is also difficult to reconcile the response preparation hypothesis with the data of Bernstein et al. (1970) and Morrell (1968a) which showed a significant dRT to occur when the irrelevant auditory stimulus preceded the visual stimulus by 40 msec. This stimulus sequence places the central arrival time of the irrelevant stimulus about 80 msec ahead of the visual stimulus and should result in maximal dRT and FAR measures; yet neither measure was maximized, nor significantly different from their value when the critical stimulus led the irrelevant stimulus by 40 msec (see also Taylor, 1974).

The appeal of Bernstein et al. (1973) to a dual process explanation to account for their results seems weak, particularly when one of the processes leads to predictions in opposition to the results. Also, the relationship between the Energy Integration model and response preparation effects is not made clear, although the two processing schemes are postulated to affect the identical response to identical stimuli simultaneously. Since the response preparation hypothesis is unable to accommodate the FAR difference between the two foreperiod durations, and the relationship between response preparation and energy integration effects is unclear, the proposal of a two-process explanation of Bernstein et al.'s (1973) data would appear to present more of a problem than a solution.

There is no definite reason, however, why the two processes must be treated as separate systems. In fact, a merger of the two ideas into a single processing system provides a construct in accord with Bernstein et al.'s (1973) data. If the response preparation process is assumed to increase the evocation criterion value of the intensive channel as the foreperiod duration increases (as temporal uncertainty increases), long foreperiod delays would result in high criterion values and large RTs. An increase in the criterion value means the irrelevant stimulus contributes its intensity component to the intensity integration channel for a longer period of time; thus a greater dRT value is expected. The decreased FAR at the longer delay results from the increased evocation criterion value: When the evocation criterion is set at higher values the likelihood is decreased that an irrelevant stimulus alone would be sufficient to evoke a response. This interpretation of foreperiod duration effects, coupled with Bernstein et al.'s (1973) interpretation of intensity effects, permits the results of Bernstein et al. (1973) to be assigned solely to a variable criterion version of the Energy Integration model (for a discussion of variable criterion models and their application, see Grice, 1968, 1972).

Quality processing.

If the intensive component of a stimulus is processed by one channel, what is processed by the other channel? Bernstein et al. (1970) rather vaguely suggest the second channel performs a pattern analysis of the critical-modality stimulus, but Simon and Craft (1970) offer evidence that the quality processing channel is sensitive to stimulus features other than just those of the critical-modality stimulus. Simon and Craft presented their subjects with simultaneous auditory and visual stimuli in a manner similar to the studies discussed above, although they complicated the task somewhat: Two lights were mounted on either side of center which could be turned on and off, and when depressed, served as response keys. Auditory stimulation could be present or absent; when present, auditory stimulation could be in both ears or to either ear alone. This design incorporated two new manipulations: a choice between responses, as opposed to responding or not responding (go-no go), and monaural presentation of the irrelevant stimulus. The subject's task was to respond to the onset of a light by depressing it. The RT results indicated that monaural auditory stimulation had an effect beyond simple RT facilitation. Where the Energy Integration model would predict lower dRT values on monaural trials (compared to the higher-energy binaural trials), Simon and Craft found that the ear stimulated interacted with the light lit. When the ear stimulated was on the same side of center as the light onset, dRT was increased; when the ear and light were on opposite sides, dRT was decreased. Simon and Craft thought that this monaural stimulation effect was due to a tendency of the subjects to respond towards the source of stimulation, so that when the stimuli were ipsilateral to one another the response was facilitated, and when the stimuli were contralateral to one another the response was impeded. Moreover, it was evident that these effects occurred about a baseline established by the irrelevant stimulus intensity effect, ipsilateral trials were responded to more quickly, and contralateral trials were responded to more slowly, than binaural trials.

Simon and Craft's experiment is, however, confounded by the use of lights as both the visual stimuli and response locations. It is not clear whether the monaural trial effects result from the relative compatibility and incompatibility of the two stimuli, the two response tendencies, the three spatial locations, or some combination of each. How the effect was produced is theoretically of importance.

The effect of monaural stimulation may have been the result of a locational comparison between the entry points of the two stimuli. Before the tendency to respond to one side or the other was formed, the comparison process might facilitate or impede the formation of a response tendency. When the stimuli were ipsilateral to one another, formation of a response tendency to that side might be enhanced, when the two stimuli were contralateral to one another, formation of a response tendency to the light side might be impeded. In the case of contralateral inputs a second process might be performed to determine which of the locational inputs was the stimulus crucial to the task. This interpretation requires the comparison of locational information to occur prior to the selection of a response.

A second possibility would be that the monaural stimulation effect results from a comparison of response tendencies. If both the visual and auditory stimuli were to evoke tendencies to respond toward their location, a comparative process between the two might allow compatible tendencies to be enacted but require a resolution between incompatible tendencies. Resolution might occur by the discrimination between auditory and visual stimulus-generated tendencies; but in any event this view proposes discrete processing of modality inputs until after the response tendency is formed.

A third possibility is that the two stimulus locations interact with the response location. Like the first suggestion (stimulus-stimulus interaction), the interaction between three locations implies that a spatial comparison occurs prior to response selection. This suggestion, however, also includes the location of the response keys in the comparatve process. If the response were not one of left or right, the eccentricity of the stimuli from center may not have an effect on response performance.

An experiment from which support for the third interpretation may be derived was conducted by Bernstein and Edelstein (1971). They used two lights, one above the other, and two tones, of different pitches, as stimuli. The tones were defined as irrelevant to the task, and the subjects were instructed to respond to the upper light by pressing a response key to the right and to the lower light by pressing a response key to the left (or vice versa). Obviously above and below do not map spatially onto left and right, yet Bernstein and Edelstein found faster responses to occur when the position of the light was similar to the pitch of the tone (eg. high-high) than when it was not. (It is interesting to note the correspondence of this task and its results with the Stroop effect: Stroop, 1935.) Since the tones were always delivered binaurally through headphones, and since auditory spatial localization is a function of inter-ear comparisons of phase and pitch (Uttal, 1973), it is unlikely that any locational cues were present in the auditory stimuli. Hence it would seem that the stimulus interaction only occurred after some degree of stimulus processing had converted the two inputs into like codes. It is reasonable to assume the codes would be of a form similar to a response tendency (as opposed to a response selection).

The suggestion that only stimulus locations interacted may be rejected on the basis of experiments by Taylor and Campbell (1976) and Campbell and Taylor (1974). These researchers found monaural and binaural irrelevant auditory stimuli to result in virtually identical RTs when subjects responded with the index and middle fingers of their right hand, though both types of stimulation produced significant dRTs. Since Taylor and Campbell presented visual stimuli to the left and right of fixation and failed to find an interaction between the visual and auditory stimulus locations, the disposition of Simon and Craft's (1970) interaction seems to be one of a somewhat primative discrimination between responses -- rather than stimuli. Apparently only when a gross differentiation exists between alternative responses does the locational component of stimuli become salient to response performance. The finer discrimination between fingers of the same hand did not provide the environment necessary for the locational interaction to occur. It may be that a between-hemisphere comparison of response tendencies is necessary.

The conclusion must be reached, however, that, contrary to the tenets of the Energy Integration model, the irrelevant stimulus is processed for quality as well as for intensity, though quality processing seems to be a relevant task consideration only when the response-performance characteristics are highly differentiated. In the simpler go-no go tasks used by Bernstein et al. (1970, 1973), Morrell (1968a, 1968b), and Todd (1912) intensity was the only feature common to both the critical and the irrelevant stimulus; in the more complex tasks of Simon and Craft (1970) and Bernstein and Edelstein (1971) which required a forced choice to be made, the locational properties of both stimuli and responses were found to interact; and when the locational feature was marginal (Taylor and Campbell, 1976; Campbell and Taylor, 1974) it had no effect on RT.

That stimuli supposedly irrelevant to a task can affect a person's performance of that task is not surprising. Experiments using dichotic presentation of text, which require the subject to repeat the text presented to one ear, find that the more similar the texts, the more often intrusions from the irrelevant text occur in the subject's recital (Treisman, 1960, 1970; Underwood and Moray, 1971; Smith and Groen, 1974). Other studies using dichotic presentation have found that the material presented to the irrelevant ear intrudes in memory tasks (Lewis, 1970; Norman, 1969), is attended to when subjectively pertinent (Moray, 1959), and can be categorized in terms of voice pitch and other gross categories (A. Treisman, 1964). When subjects are trying to read aloud a list of digits presented visually, the auditory presentation of a different list of digits disrupts performance (Greenwald, 1970). It is evident that, to some extent, the stimulus defined as irrelevant to the task is processed for more than intensity.

The Energy Integration model, with its assumption of discrete channel function, is inconsistent with the effects of irrelevant stimulus features. To account for these effects a model other than the Energy Integration model must be posed. Initially the new model must be able to account for the effects discovered in the go-no go experiments (eg. Bernstein et al., 1970, 1973); subsequently it must be adaptable to accommodate the results of the forced-choice experiments (eg. Simon and Craft, 1970); and finally it should be able to generate accurate predictions in new experimental situations. A model to fit the initial requirement might be built by incorporating the intensity processing ideas of the Energy Integration model with the evocation criterion ideas from recent response-preparation models (Geller, 1974; Thomas, 1974) and variable-criterion models (Grice, 1968, 1972).

The Information Integration model

The model to be presented is in no way intended to be anything more than an initial attempt to incorporate the above cited effects of intersensory stimulation on RT into a single conceptual framework. The term 'model' is used in two ways: 1) a series of hypothetical mechanisms will be proposed as means of deriving the intersensory effects, these mechanisms and the links between them will form a heuristic, conceptual model; 2) these mechanisms will also be presented graphically, represented by boxes and links between boxes to form a schematic model. The conceptual model (or the schematic model with its conceptual underpinnings) will be designed to be capable of generating both a priori and a posteriori qualitative predictions: a priori because once the model is constructed the ramifications of its form will be apparent, and a posteriori by virtue of the considerations involved in its construction.

The model will be constructed in two steps. The first step will be to build a form of the model sufficient to account for the go-no go experimental data, and the second step will be to elaborate the first step model to account for the forced-choice experimental data.

The Information Integration model: Step One. Any model of stimulus processing in a task situation needs three basic stages: a sensory interface, a central processing unit, and a motor response interface (Sternberg, 1969). For each of these processing sections certain assumptions must be made as to the function of the section; these assumptions will be instantiated by the postulation of hypothetical mechanisms, the presence of which seem indicated by the data. The primary function of the Step One model will be to account for the dRT found when a mixed block of noisy (critical and irrelevant stimuli) and quiet (critical stimulus alone) trials is presented. The Step One model will also be required to offer a systematic account of FAR production, the direct relation between the intensity of the irrelevant stimulus and dRT, and the inverse relation between the intensity of the critical stimulus and dRT (Bernstein et al., 1973).

Figure 2 shows the schematic representation of the Step One conceptual model.

Sensory interface. The sensory interface transduces physical sensations into representational neural pulses independently by input locus and provides for the isolation of one locus as critical. In Figure 2 the transducers are represented as generators (g1, g2, g3, ..., gN) and the selection mechanism(s) as switches (s1, s2, s3, ..., sN). The generators are assumed to pulse neural information at a rate (frequency) proportional to the intensity of the stimulus input (Uttal, 1973), increasing their pulse rate about the onset and offset of a stimulus. The selection switches are assumed to rest at the non-critical setting with the option that one and only one switch may be set on critical at any one time (cf. Kristofferson, 1967).

Central processor. The central processor decreases the relative weight of information received from the non-critical generators, monitors the cumulative number of neural pulses received, and actuates the response when a predetermined number of pulses have been processed -- that is, when the evocation criterion has been attained. In Figure 2 all non-critical generators (g2, g3,..., gN) are shown with their switches in the resting position; their output is merged and routed to the frequency attenuator. The output of the critical generator (g1) is routed (by switch s1) directly to the accumulator where it is merged with the output of the other generators.

The frequency attenuator serves an important purpose in this model. Its function is simple, it removes some proportion of the pulses from the pulse trains of the non-critical generators, thereby preserving the

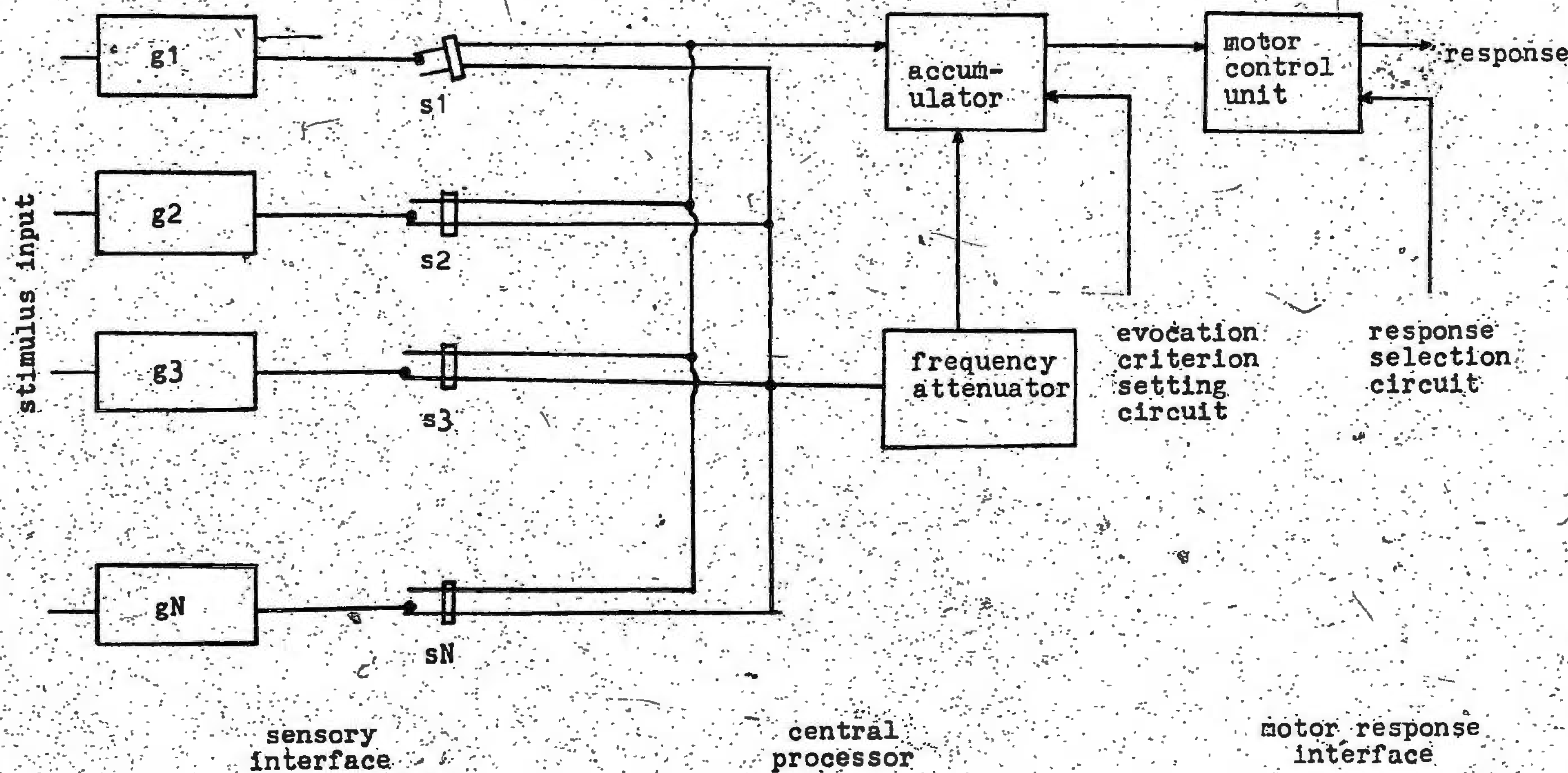

Figure 2

The Information Integration model. The generators are represented as g(i), the switches as s(i). See text for an operational description. The model is shown as if g(i) is the critical generator.

non-critical information while decreasing the non-critical pulse rate relative to the unattenuated critical pulse rate (cf. Deutsch and Deutsch, 1963).

The accumulator stores the number of pulses which reach it within some unit of time. If the pulse count is to be retained over time units the number of pulses received must exceed some critical value. That is, if the critical number of pulses is not received the accumulator is voided. Thus very weak signals and spontaneous generator discharges do not contribute to the accumulator unless accompanied within the time unit by a stronger signal. Irrelevant signals will, of course, be much weakened by the attenuation process, and they are assumed not to contribute to the accumulator except during their onset or offset or when they are accompanied by the critical stimulus. Those pulses which are stored are summed towards the evocation criterion. When the evocation criterion is reached the accumulator sends a trigger signal to the motor response interface to enact the response (see McGill, 1967; Luce and Green, 1972).

Motor response interface. The motor response interface transduces the neural activity of the central processor into motor activities. The neural equivalent of a set of motor activities is held in the motor control unit (see Figure 2) until the reception of the central processor trigger signal, at which point the motor commands are enacted (cf. Keele, 1973; Miller, Galanter, and Pribram, 1960; Sperry, 1952). Since in a go-no go experiment there is only one (or no) response to be made, the motor control unit is assumed to be programed by the respondent before the initiation of a trial.

Evocation criterion setting circuit. The evocation criterion setting circuit determines the number of generator pulses that must be processed before the trigger signal is sent from the central processor to the motor control unit. This creates a speed-accuracy trade off between processing more pulses to boost accuracy and processing fewer pulses to speed the response.

The evocation criterion is assumed to be set volitionally by the respondent in accordance with task instructions (Luce and Green, 1972; Thomas, 1974), stimulus discriminability (Garner and Morton, 1969; Norman and Bobrow, 1975), and independent between-trial reassessments of speed-accuracy optimization. The between-trial reassessments are assumed to be most important as the respondent is learning the task, and to follow the general rule of lowering the criterion after a correct response and raising the criterion after an incorrect response (see Geller, 1974). These fluctuations of criterion value are assumed to diminish in both frequency and extent with practice, eventually stabilizing about an optimal value. The respondent's primary consideration in selecting the optimal criterion value is assumed to be the most frequently occurring stimulus-response pair (Mowrer, 1944; Geller, 1974) or the most frequently occurring manipulation affecting the accuracy of responses (eg. catch trials).

The evocation criterion is not, however, assumed to remain constant throughout the duration of a trial. The operating value is assumed to increase as a direct function of temporal uncertainty (Bernstein, 1970) from the set value to some resting asymptote.

Qualitative predictions of the Information Integration model. The main purpose of the model, prediction of the dRT found between quiet and noisy trials in a mixed-trial block, is met by the stipulation that a response-evoking trigger signal is sent when the evocation criterion is reached. Since the respondent has no foreknowledge of whether a noisy or quiet trial will occur, the evocation criterion may be expected to be at the same (mean) value for either type of trial; thus, on noisy trials added pulses emitted from the irrelevant generators will augment the pulse rate of the critical generator, resulting in the attainment of the evocation criterion more quickly than on quiet trials. The general prediction follows that the more active the irrelevant generators, the greater the dRT. And also, the greater the intensity of the critical stimulus the lower the relative contribution of a given irrelevant stimulus intensity to the accumulator; hence the interaction between critical and irrelevant stimulus intensities found by Bernstein et al. (1970, 1973) is predicted by the Information Integration model. (Bernstein et al. used the dual concepts of preparation-enhancement and the Energy Integration model to account for these results; however, the two concepts are difficult to relate to one another, and the Information Integration model obviates that difficulty.)

As pointed out earlier, Bernstein et al. (1973) were unable to adequately explain their FAR results with either preparation-enhancement of Energy Integration arguments. This gives rise to what may be the crucial rationale for the Information Integration model at this point. FAR was found to be positively correlated with dRT when the irrelevant stimulus intensity was varied, and negatively correlated with dRT when the foreperiod duration was varied. Bernstein et al. did not offer a dual-process explanation for this interaction. Although the Energy Integration model predicts that an increase in FAR follows from an increase in irrelevant stimulus intensity, the decreased FAR resulting from an increase in foreperiod duration is an enigma which does not easily fall within the contexts of response-preparation or energy integration. Clearly the Energy Integration model cannot account for the conjunction of an FAR decrease with a dRT increase since it proposes that the irrelevant stimulus causes an increase in neural excitement spurious to critical stimulus detection. The Energy Integration model would necessarily predict FAR and dRT to be positively correlated. And, because response preparedness increases as the result of a task-irrelevant input (Bernstein, 1970), the notion of preparation-enhancement would also predict a positive correlation between FAR and dRT.

A provision built into the Information Integration model is that the evocation criterion increases as a function of foreperiod duration. The prediction that FAR decreases and dRT increases as a result of lengthening the foreperiod duration is a consequence of an increased evocation criterion. The dRT prediction derives from the increased period of time irrelevant generators contribute pulses to the accumulator, and the FAR prediction derives from the elevated evocation criterion being less attainable with only irrelevant (attenuated) stimulus input.

The evocation criterion assumption of the Information Integration model lead to other predictions. Since false alarms are attributed to low evocation criterion settings, repondents attempting to maximize accuracy would be expected to set their criterions higher during blocks of trials in which irrelevant stimulus intensity is greater (or present) compared to those trials in which it is lesser (or absent). Nickerson (1970) found that RT_V is slower during blocks of mixed quiet and noisy trials than in blocks of quiet trials alone. Between-block comparisons of RT_V using different irrelevant stimulus intensities have not been made (the intensity manipulation has, thus far, only been a within-block manipulation).

The last finding that the Information Integration must account for is the roughly symmetric distribution of dRT about an ISI of zero (Bernstein et al., 1970). The assumption has been made that a critical number of pulses must reach the accumulator within a single time unit or the accumulator will be voided. Since the irrelevant generators' outputs are attenuated, it is only during their peak output periods (stimulus onset and offset) that they will be assumed able to surpass this critical value within one time unit; the onset or offset of the irrelevant stimulus must occur within one time unit if it preceeds the critical stimulus, or before response evocation if it follows the critical stimulus. Hence, the irrelevant stimulus will have its greatest effect when either its onset or offset corresponds with the onset of the critical stimulus, and a roughly symmetric distribution of dRT about zero ISI is expected.

The Information Integration model: Step Two. The Information Integration model in its Step One version seems able to accommodate the data found in go-no go experimentation. However, it cannot account for forced-choice experimental data (eg. Simon and Craft, 1970) without elaboration of the response selection circuit and insertion of a mechanism with the capability to process quality information. Consider the present form of the model (Figure 2). There is no means for selecting a response on the basis of stimulus quality. Nor can quality analysis be done.

Figure 3 illustrates the Step Two model. The only reconfiguration in the sensory interface is the replacement of the single frequency attenuator with individual attenuators, each devoted to a single generator.

The central processor has been elaborated by the addition of a feature selector, feature analyzers, and a response selector. The purpose of the feature selector is to partition the incoming generator pulses into elemental features, and to direct the feature information to the appropriate feature analyzer. The feature analyzers evaluate the feature information and translate it into a neural code which can be matched to the neural motor program representations in the response selector. Once the response selector has matched the feature information to a motor program, the program is stored in the motor control unit. Enactment of the program occurs when the accumulator sends its trigger signal, as in the Step One model. The accumulator in

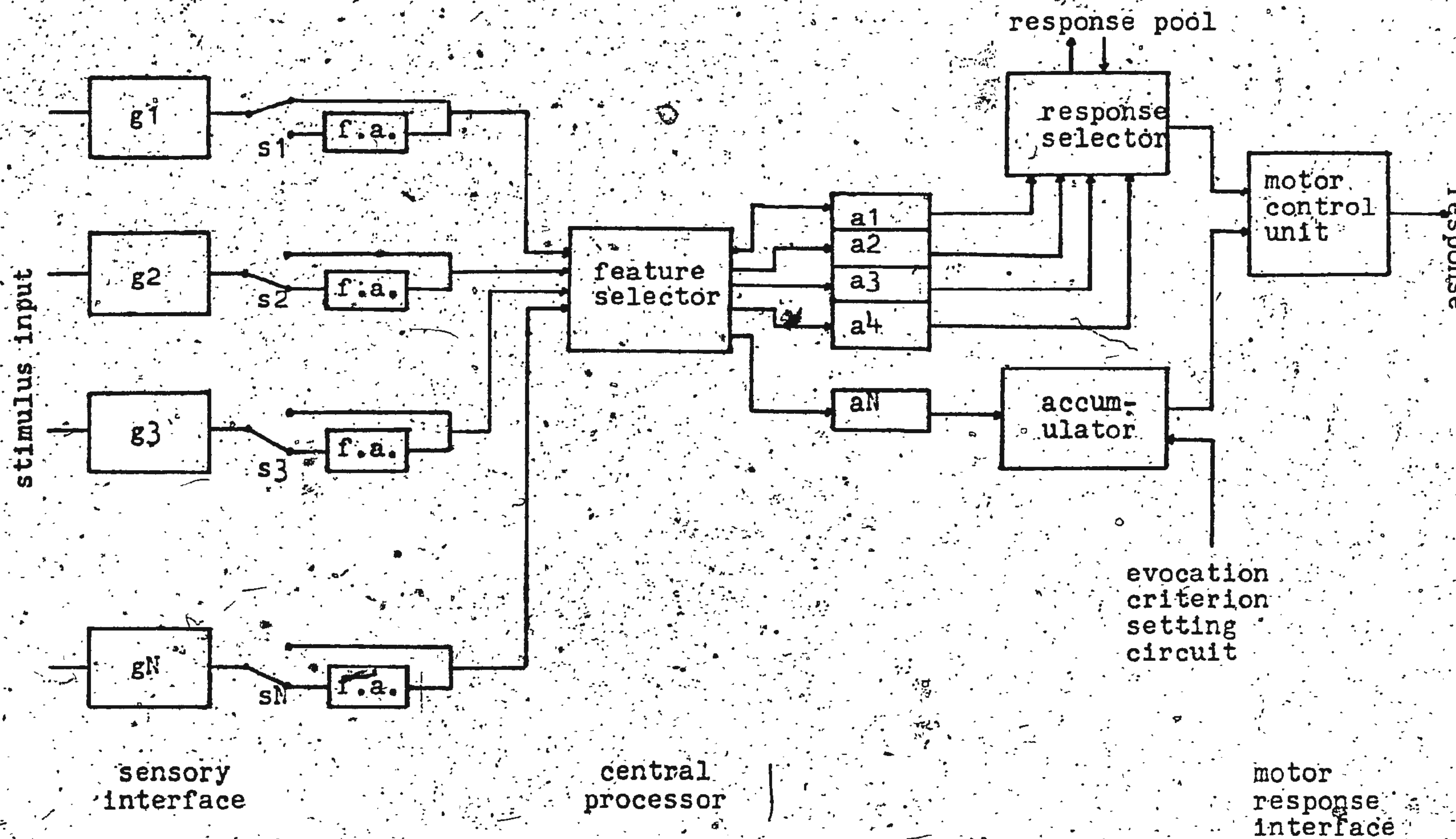

Figure 3

The Information Integration model (redesigned). The generators are represented as g(i), the switches as s(i), the frequency attenuators as f.a., and the feature analyzers as a(i). See text for an operational description.

the Step Two model receives its input only from the feature analyzer processing intensity (aN in Figure 3), but otherwise functions as in the Step One model.

As the earlier discussion of forced-choice experiments pointed out, the ear of irrelevant input (Simon and Craft, 1970) or the pitch of an irrelevant tone (Bernstein and Edelstein, 1971) can significantly affect the speed of a left-right or high-low forced-choice response. As a consequence of these findings the Step Two model must provide means for qualitative properties of the irrelevant stimulus to be processed. However, in a yes-no forced-choice matching task, with the responses made with different fingers of the same hand (Taylor, 1974), there is not a significant dRT difference between presentation locations of monaural tones or tone pitches. Clearly, features of the irrelevant stimulus are processed, but only if they are also features of the critical stimulus or response characteristics do they affect RT. The Information Integration model includes mechanisms to isolate and evaluate feature data in order to account for these results. The issue here is the function of the mechanisms, not their external validity.

The schematic diagram of the Step Two model (Figure 3) shows a series-parallel circuit. The information input at the generators, frequency attenuation, and the analysis of different features are all parallel processes; while feature selection, response selection, and the analysis of individual features are all serial processes. Processing bottlenecks might occur in the circuit where several information pulses converge on a single mechanism (cf. Broadbent, 1958); for example, when several generators output high intensity (rapid rate) information simultaneously, a bottleneck might occur at the feature selector which must operate serially on single pulses. As a rule, whenever a parallel process feeds into a serial process a potential bottleneck exists.

Bottlenecks are considered to be manifestations of the systemic limitations which set the minimum processing time limit (Garner and Morton, 1968; Norman and Bobrow, 1975). In the Information Integration model, bottlenecks set the minimal processing time limit by restricting the rate of information flow through the feature selector. When the feature selector is blocked the accumulator cannot receive intensity information and the trigger signal cannot be sent.

Assuming information flows through the system, a response must be selected from the choices offered the respondent. The selection of a response depends on four factors: the contents of the response pool, the output of the feature analyzers, a matching procedure, and a random walk analysis (Laming, 1968) of the matching results over some unit of time (see luce and Green, 1972; McGill, 1967). The contents of the response pool are assumed to be the response choices existing as neural command sequences (i.e. motor programs). The feature analyzers' evaluations are coded into a format compatible with the motor program coding format and sent to the response selector. In the response selector, the coded features are compared to the motor programs in the response pool. If the coded feature matches a motor program, then the stimulus input has indicated a certain response. The response selector is assumed to sum matches over a unit of time (equivalent to the unit of time used to void the accumulator in the Step One model) while performing the random walk analysis. If the analysis indicates a response, the motor control unit is programed with the motor program associated with that response (the motor program which was matched). The motor control unit holds the response until either the trigger signal is received from the accumulator or the response selector alters the motor programing.

Response control of the model relies on the increased probability that the critical stimulus will determine response selection after the irrelevant generators' output has been attenuated. Since the information carried by the irrelevant stimulus (stimuli) has not been eliminated it is possible that an irrelevant generator might contribute the information determining the contents of the motor control unit. This would occur if both a feature of the irrelevant stimulus could be matched to a response code and more irrelevant generator pulses were matched than were critical generator pulses during a time unit. If the evocation criterion is reached while the motor control unit contains a motor program evolving from an irrelevant input, the evoked response may be incorrect. If the evocation criterion is not reached before critical stimulus features control response selection, the motor control unit may have to be reprogramed, increasing processing time.

The basic assumption of response storage and response selection selection have important consequences to the operation of the Information

Integration model. As stated above, responses are assumed to exist as motor programs, and are compared to feature information during response selection. A comparison between feature information and response codes requires that the two be encoded in the same format; since the basic form of a response is a series of neural motor commands, it has been assumed that feature data is transformed by the feature analyzers into an associated motor program code appropriate to the task. The more direct the association between feature and response, the shorter the time taken by the translation process. For example, the translation of a red, centered light into a right-hand response code would take longer than the translation of a light to the right of center into a right-hand response code. This argument treats stimulus-response compatibility effects (Fitts and Seeger, 1953; Keele, 1968; Simon and Craft, 1970) as resulting from more (or less) efficacious translation of features into their associated response codes: This implies that, not only will translation time affect decision time, greater numbers of features producing response codes will complicate the response selection phase by adding more operations per unit input and result in slower task performance, particularly when a match is not found (cf. Sternberg, 1969). In a task where right and left hand responses are determined by auditory commands of "right" and "left" monaurally presented to the left or right ear (Craft and Simon, 1970), the Information Integration model would consider both the symbolic content of the command and the ear of input as relevant feature to response selection since both contain information about laterality, and thus can be associated to a lateralized response. Also, the ear of input (the implicit information content of the stimulus) would be analyzed more quickly than the symbolic content since the translation from stimulus location to response location is more direct. Consequently the model would predict those trials in which the command and the command location agreed (eg. "right" to the right ear) to produce lower RTs than those trials in which the symbolic and implicit information disagree (eg. "right" to the left ear).

The Information Integration model offers a system from which qualitative predictions about RT and error rate (ER) can be derived. Given the basic RT relationships between stimuli and responses found in detection experiments (eg. simple auditory stimuli are responded to more quickly than simple visual stimuli: Woodworth and Schlossberg, 1954), the model generates definite relational predictions from complex stimulus situations. For Simon and Craft's (1970) study the predicted relationships are $RT_{ma} < RT_{s} < RT_{md}$ and $RT_{ma} < RT_{s} < RT_{V}$ (where ma, s, and md represent monaural agree, stereo, and monaural disagree, and V represents visual). The Information Integration model analysis of these trial types resulting in the above predictions is: 1) $RT_{s} < RT_{V}$ since stereo (binaural) auditory input adds more pulses to the accumulator per time unit; 2) $RT_{ma} < RT_{s} < RT_{md}$ since, compared to stereo trial types, when an irrelevant stimulus carries feature information critical to the response decision (i.e. matching response characteristics), the decision time will be less when the information concurs with, and greater when the information conflicts with, the information about that feature carried by the critical stimulus. The relationship between RT_{md} and RT_{V}

cannot be predicted since the time relationship between reprograming the motor control unit, or increased response selection time, is considered to determine RT_{md}, and it is not known how this will change the RT relationship between bisensory and unisensory stimulation.

A more challenging set of results to predict are those of Bernstein and Edelstein (1971). When Simon and Craft invoked the stimulus-response interpretation of their results, they effectively ignored processing of the irrelevant stimulus and preempted the justification of an information model. However, the results of Bernstein and Edelstein showed that when the symbolic information of two stimuli coincide on a stimulus feature (vertical location), the response to consistent feature information is more rapid than the response to inconsistent feature information. Since the irrelevant auditory stimulus transmitted location information by pitch rather than physical location, a stimulus-response compatibility interpretation of response facilitation would seem inappropriate unless some processing of the irrelevant stimulus were involved. That the same information analysis argument used to account for Simon and Craft's results (above) can be applied to account for Bernstein and Edelstein's results gives credence to the notion that the Information Integration model is a more general conceptual tool than either the Energy Integration model or stimulus-response compatibility interpretations, *per se*.

An empirical test of the Information Integration model.

The true value of a model is not simply its generality in offering accounts of data already obtained, but rather in its ability to predict experimental results a priori. A rigorous test of the Information Integration model was devised. Three conditions were used, auditory-only (A), visual-only (V), and auditory-visual (AV), and two responses, a right-hand and a left-hand keypress. The stimuli used in the A and AV conditions were constructed to contain overlapping features which were manipulated into several levels of concord and conflict, while maintaining a clearly correct response choice. In the V condition only one level of concord was used, the A condition contained three levels, and the AV condition contained the same three levels of concord as the A condition plus one level of conflict. Manipulation of concord and conflict was done through the use of dichotic auditory presentation: in stereo (S) trial types both ears reveived the same, task relevant stimulus; in Monaural (M) trial types one ear reveived a task-relevant stimulus while the other ear received no input; in irrelevant (I) trial types one ear received a task-relevant stimulus while the other ear received a task-irrelevant stimulus; in conflicting (C) trial types one ear received the task-relevant stimulus associated with one response while the other ear received the task-relevant stimulus associated with the other response.

Predictions about performance using the stimulus-response configurations described above can be derived from the Energy Integration model, stimulus-response compatibility interpretations, and the Information Integration model. The predictions which are derived from the Energy Integration model often conflict with those from the

Information Integration model, and that the Information Integration model offers a richer set of predictions than either of the two existing accounts of intersensory processing.

I. Within the A condition.

A. Information Integration model predictions.

1. $RT_s \approx RT_m < RT_i$
2. $ER_s \approx ER_m < ER_i$
3. $RT_{ma} < RT_{md}$
4. $RT_{id} < RT_{ia}$

These predictions are derived from the following trial type analysis.

S trial types. Every S trial will contain both left and right location indications due to binaural input. This implicit indication will be concurrent with symbolic information, and thus response selection will be slowed for those samples from the ear in which the implicit and symbolic information disagree.

M trial types. Half of the M trials will contain symbolic and implicit information which agrees (MA trials), half of the M trials will contain symbolic and implicit information which disagrees (MD trials). Thus the mean RT for M trial types should be equivalent to the mean RT for S trial types, and the MA trials should be responded to more quickly than the MD trials. The absence of input to one ear may, however, slow the sample rate such that $RT_s < RT_m$.

<u>I trial types</u>. Every I trial type will contain implicit information which conflicts with the symbolic information. When the task-relevant stimulus contains implicit and symbolic information which agrees (IA trials), the task-irrelevant stimulus will carry the conflicting location information; since the irrelevant sample's implicit information will not be accompanied by symbolic information, the motor control unit may be programed with the incorrect response pattern. When the task-relevant stimulus contains the conflicting information (ID trials) the implicit information carried by the task-irrelevant stimulus will agree with the symbolic information of the task-relevant stimulus; while response selection will be slowed for ID trials, the incorrect response will not be selected and the motor control unit will not need reprograming when the symbolic information is received. ID trials, however, are expected to require more processing time than MD trials since the feature analysis for symbolic content of a stimulus input (auditory) which may carry the task-critical feature has been found to take longer when the feature is absent (Sternberg, 1969). The absence of the task-critical feature will occur always for both IA and ID trials. Since motor control unit reprograming is assumed to consume more time than response selection delays, ID trials are predicted to be responded to more swiftly than IA trials. In that IA trials are the only A condition trials predicted to produce spurious

motor control unit programs, the I trial types are predicted to produce more errors than either the S or M trial types. However, the prediction $ER_{id} < ER_{ia}$ is not made for four reasons: 1) the sampling time unit is not known, 2) the effect of a fruitless feature analysis may involve unanticipated motor control unit manipulation, 3) the right-ear superiority effect (Studdert-Kennedy and Shankweiler, 1970) may confound ER effects, and 4) a high evocation criterion setting may confound ER effects. These issues will be dealt with later.

B. Energy Integration model prediction.

$RT_s \approx RT_i < RT_m$

This prediction is derived from analysis of the energy content of the trial types. S and I trial types give auditory input to both ears, M trial types give auditory input to only one ear. No error rate predictions may be made in a choice situation since the quality processing channel's method of operation is unknown.

C. Stimulus-response compatibility prediction.

$RT_{ma} < RT_{md}$

This prediction is taken from Simon and Craft (1970).

II. Within the AV condition.

A. Information Integration model predictions.

1. $RT_s \approx RT_m < RT_i < RT_c$

2. $ER_s \approx ER_m < ER_i < ER_c$

3. $RT_{ma} < RT_{md}$

4. $RT_{id} < RT_{ia}$

In that the auditory signals are expected to arrive centrally before the visual signal (Morrell, 1967), and sampling of the auditory input is assumed to continue even after the visual input has arrived at the central processor, these predictions follow the rationale of the A condition predictions for the S, M, and I trial types. The C trial types are expected to produce larger RTs and ERs than all other trial types since C trials will always induce motor control unit reprograming. C trial types will always contain conflicting symbolic information.

B. Energy Integration model predictions.

1. $RT_s \approx RT_i \approx RT_c < RT_m$

2. $ER_s \approx ER_m \approx ER_i \approx ER_c$

The C trial types contain as much energy as do the other binaural trial types and more than the M trial types, therefore RT_c should be equal to RT_s and RT_i and lower than RT_m. Since the visual stimulus will always be correct, and the auditory stimuli may conflict, the visual channel will be assumed to be the quality processing channel; hence, the auditory channel will be used solely as an energy source, the quality of the auditory channel input should not affect ER.

C. Stimulus-response compatibility prediction.

$RT_{ma} < RT_{md}$

III. Between conditions.

A. Information Integration model predictions.

1. $RT_A < RT_{AV}$

2. $RT_A < RT_V$

3. $ER_{AV} < ER_A$

With the inclusion of a visual stimulus and conflicting auditory stimuli, the Information Integration model predicts an increased evocation criterion to be established so that the subject may avoid responding before the visual stimulus controls motor control unit programing. Thus RTs in the A condition are predicted to be lower than RTs in the AV condition. The auditory stimuli are assumed to arrive centrally sooner, and carry more energy, than the visual stimulus; these assumptions lead to the prediction that RT_A will be less than RT_V. Finally, the increased evocation criterion found in the AV condition should result in fewer errors for those trial types in common between the A and AV conditions (S, I, and M). The error reduction should result mostly from an I trial type ER decrease, while S and M trial types will be minimal in both conditions (i.e. the ER results should not be ascribed simply to the presence of the visual stimulus <u>per se</u>). The ER_I decrement between the conditions is assumed to occur because the motor control unit alterations will be decreased upon the arrival of the (unattenuated) visual signal.

B. Energy Integration model prediction.

$RT_{AV} < RT_A < RT_V$

The Energy Integration model predictions follow the inverse relationship between energy and RT predicted by the model.

C. Stimulus-response compatibility predictions.

none

In the above list of predicitons ma, md, ia, and id represent monaural agree, monaural disagree, irrelevant agree, and irrelevant disagree (see text). "Agreement" is defined as occurring when the task-relevant stimulus is presented only to the same side of the body as the response hand. Those predictions indicating equivalent and/or unknown RT and ER relationships are omitted except when they are the manifestations of a particularly important model tenet.

The Information Integration model predictions follow the assumptions that (1) a random presentation of trial types within a block of trials (condition) produces a stable evocation critierion and amount of frequency attenuation, and (2) between conditions the evocation criterion will be changed to accommodate changes in the number of response-associated features transmitted by the different stimuli. Assumption (1) implies that RT and ER differences between trial types are generated by time delays and premature responses occurring when irrelevant stimulus input controls response selection. Assumption (2) implies RT and ER differences between conditions will follow a speed-accuracy tradeoff function.

These predictions are somewhat complicated by two factors: a right-ear (left cerebral hemisphere) superiority effect for the processing of letter stimuli (Studdert-Kennedy and Shankweiler, 1970), and the superiority of dominant-hand responses in bimanual tasks (only right-handed subjects will be used). These two inconveniences will be manifest as the attenuation of differences favoring left-hand responses and the augmentation of differences favoring right-hand responses. Biased processing may also be found when symbolic and location (implicit) information is contraposed between ears.

EXPERIMENT I

Method

Subjects. The subjects were 12 university students (7 female) who volunteered for the experiment. They were each paid two dollars an hour for five hours service, an hour a day for five consecutive days. All subjects were right handed and had no uncorrected seeing or hearing defects.

Stimuli. The auditory stimuli consisted of a 1000 hz tone and the spoken letters "A" (/e/), "E" (/i/), and "O" (/o/) recorded in a male voice. These four sounds were each recorded once, and that recording was used as the source for all auditory stimuli. By re-recording the source tape onto a second tape recorder, the stimulus prototypes were combined to form the various trial types.

Four trial types were formed from combinations of the three letters. Stereo (S) stimuli were recordings of either "A" or "E" on both channels of a two-channel tape recorder; Monaural (M) stimuli were recordings of "A" or "E" on one channel while the other channel was left silent; Irrelevant (I) stimuli were recordings of "A" or "E" on one channel and "O" on the other; and Conflicting (C) stimuli were recordings of "A" on one channel and "E" on the other channel. By measuring the length of tape between sounds, temporal sequencing was controlled such that the 1000 hz tone could be inserted a standard one second before all letter combinations as a warning stimulus, and by slowly drawing the tape underneath the pick-up head of the tape recorder, the simultaneity of the letters was assured.

Seven recordings (2S, 2M, 2I, and 1C) were made in this manner. These recordings were then duplicated on a third tape to balance the channel of letter presentation for M, I, and C trial types by alternating the patch cord leads between tape recorder channels. Thus, a total of twelve letter combinations were made; the specific letter presented and channel of presentation within a trial type (eg. a M trial type using the letter "A" presented on the left channel) will be referred to as a trial type subgroup. The twelve letter combinations were then randomly selected to form the trial type sequences used in the experiment. Four tapes to be used in the auditory-only (A) condition and four tapes to be used in the auditory-visual (AV) condition were constructed with the restrictions that no A-condition tape contained any C trial types and eight trials of each trial type subgroup occurred on each tape. Hence, the A-condition tapes each contained 80 trials (16S, 32M, and 32I), and the AV-condition tapes each contained 112 trials (16S, 32M, 32I, and 32C). An intertrial interval of six seconds was inserted between the offset of the letter stimuli and the onset of the warning signal for the next trial. The tapes were recorded so that all stimuli were of equal intensity; which during the experiment was amplified to about 60 db SPL.

The visual stimuli were block letters (Letraset Helvetica medium 48pt), photographed on positive film (resulting in black-on-white transparencies), and center-mounted on standard (2 x 2 inch) slide mounts. The transparancies were projected onto a back-projection screen such that the letters subtended a visual angle of about 100 mrad horizontally and about 110 mrad vertically when the subject was seated 1.3 m from the screen. The stimulus intensity was determined by the projector being set on low intensity and placed 67 cm from the screen. Visual stimulus selection was controlled by a paper tape reader and random selection device programmed to correspond to the AV-condition tape or in a random sequence (for the V-condition trials).

The duration of both auditory and visual stimuli was controlled by timers set at 190 msec. All stimuli were clearly perceived at this duration.

Apparatus. A complete electronic circuit was constructed of a Sony two-channel tape recorder, a Grason-Stadler voice-operated relay, BRS timers and logic, a Kodak Ektagraphic projector with random access and mounted with a Gerbrands tachistoscopic shutter, a Lafayette random access unit and paper tape reader, two normally closed response relays, a set of Sony headphones, and a Hunter Klockounter. On each trial the tape recorder played two sounds, the warning signal and the stimulus letters. These sounds were picked up by the voice-operated relay which, by a flip-flop circuit, (1) sent a pulse on the warning signal to set the Klockounter to zero and advance the paper tape reader, and (2) sent a pulse on the stimuli to start the BRS timers and the Klockounter. The depression of a response key halted the Klockounter and lit the logic light corresponding to the depressed key. The BRS timers controlled the opening and closing of the tachistoscopic shutter and leads from the tape recorder to the headphones. During the V-condition trials the subject heard the warning tone via a between-room intercom.

Procedure. Subjects volunteered for the experiment by signing their names in the time slots of a schedule. According to the chronological order of their first time slot, the subjects were assigned to a hand group, odd-numbered subjects were told to respond to the letter "A" with their dominant (right) hand and even-numbered subjects were told to respond to the letter "A" with their non-dominant (left) hand.

Upon the subject's arrival at the experimental site he was handed an instruction sheet (Table 1, Appendix A) by the experimenter. The instruction sheet explained the subject's task, the stimuli used, and described roughly how the experiment would be run. After the subject finished reading the sheet, the experimenter asked if anything needed clarification; once the subject was satisfied that he understood the task, he was told his hand group assignment and began the practice session.

The practice session consisted of abbreviated blocks of trials, each trial type subgroup member was presented four times, otherwise all procedures were the same as on experimental days. The order of block (condition) presentation was varied between subjects and over days within subjects so that each condition was balanced in order of occurrence (Table 2, Appendix A, is the schedule of condition presentation by subject). The particular tape used to present the trials was similarly balanced during the experiment (Table 3, Appendix A).

Two adjacent chambers, each about 3 x 3 m in size, and lit by fluorescent lights, were used to conduct the experiment. The subject was seated in one room, and the experimenter was seated in the other. The two chambers were connected by a 1 x 1 m opening through which the visual stimuli were projected. All equipment was placed in the experimenter's room except the back-projection screen, the headphones, and the response keys. The experimenter merely wrote down the obtained RTs displayed by the Klockounter, made a note if an error was made, and notified the subject when a block of trials was about to begin and when a block of trials ended (subjects were asked to report their errors over the between-room intercom and were extremely accurate in doing so). Between blocks the experimenter selected the next tape to be used, mounted and positioned it in the apparatus, and informed the subject what condition it was. During tape selection and mounting the subject was given a rest period.

Design. A total of six factors, plus the subjects' factor, are included in the design: one between subjects factor, hand group, and five within subjects factors, condition (A, V, and AV), test day (1, 2, 3, and 4), trial type (S, M, I, and C), letter ("A" and "E"), and ear of letter presentation (right and left: for C trial types this was considered to be the ear in which the auditory letter corresponding to the visual letter was presented).

Results

After discarding the data from the first (practice) day and incorrect response RTs, the median RT for each trial type subgroup for each day was taken as the unit of RT analysis. The ER unit was the trial type subgroup total errors pooled over the four experimental days, divided by the number of trials. RTs were measured in msec and ERs were treated as a posteriori probability values.

The trial type and ear of presentation factors were difficult, indeed impossible, to completely cross within any one analysis since the trial types tested varied between conditions, and the ear of presentation could not be specified for S trial types or the V condition. Accordingly, the experimental data was partitioned four ways.

1) Between conditions. This partition was made to test the between conditions predictions made above. Data for this partition were taken from the within conditions analysis of variance (see below) and were the means and variances of all median RTs within each condition. Option 7 of the SPSS program ONEWAY was used to perform a three-level, one-way analysis of variance. Since the between conditions predictions all involve the A condition, it was considered the control condition for a subsequent Dunnett's test. The ER data points were treated as members of a binomial distribution (an error either occurred or did not occur). Variances were computed in the standard way (var = Np(1 − p)), and the results

were then treated in the same method as were the RT figures.

2) Between trial types. This partition was made to test the within conditions predictions made above. Data for this partition were also gleaned from the within conditions analysis of variance for the RT analysis and hand-computed for the ER analysis. The treatment of RTs and ERs involved the use of the SPSS program ONEWAY to derive an error term, then a series of contrasts (see Table 4, Appendix B, for formulae). The analyses af variance were one-way ANOVAs with eight levels. The V-condition was considered a trial type, and with the S, M, and I trial types from the A condition, and the S, M, I, and C trial types from the AV condition, all the necessary ingredients to test the predictions were available from the ANOVAs.

3) Between ears/ within conditions. Since the effects of ear of presentation could not be assessed within a balanced design which included S trial types and the V condition, this partition was made to obviate the problem and test predictions involving the ear factor. The median RTs from the M and I trial types of the A condition, and the median RTs from the M, I, and C trial types of the AV condition were used in these analyses. Thus, the analyses of variance contain the between subjects factor of Hand (hand group), and the within-subjects factors of Day, Letter, Trial Type, and Ear (ear of presentation). The conditions were analyzed separately. ERs were not examined in this partition because of the relatively few trials (8) when the data were broken down to this extent. This partition also allowed other factors in the design which were assumed to operate in the task (eg. ear and hand dominance) to be assessed.

4) Within conditions. This partition was made to provide means and variances for the between conditions and between trial types RT analyses, and to verify the non-Ear factor effects found in the between ears/ within conditions partition with the inclusion of S trial types. Also, the effects of Day, Letter, and Hand may be assessed for the V condition. This partition contains all levels of all factors except for the ear factor. Three analyses of variance were run in this partition, one for each condition. As in the between ears/ within conditions partition, ERs are not considered.

Between conditions partition results.

The mean RTs for the A, AV, and V conditions were 285, 397, and 465 msec respectively. A one-way ANOVA indicated the RTs were significantly different between conditions (Table 1, Appendix B). The Information Integration model predictions $RT_A < RT_V$ and $RT_A < RT_{AV}$ were confirmed by a Dunnett's test (Table 1, Appendix B); thus supporting the Information Integration model as opposed to the Energy Integration model. It should be pointed out, however, that the mean RT of the AV condition might be considered a spurious measure for the test of these predictions since the AV condition contains C trial types and the A condition does not. Removing the C trial types from the AV-condition data does, in fact, result in a lowered RT mean (367 msec), but a recomputation of the ANOVA and Dunnett's test does not show a significant change from previous values (Table 1, Appendix B).

The mean ERs for the A, AV, and V conditions were .0255, .0504, and .0404 respectively. These ERs do not correspond with the

Information Integration model prediction $ER_{AV} < ER_A$. However, the removal of C trial type ERs from consideration alters ER_{AV} to .0172, which does correspond to prediction. A one-way ANOVA indicated a significant difference to exist between the conditions, and a Dunnett's test confirmed ER_A was significantly higher than ER_{AV} (with C trial types removed: Table 2, Appendix B).

Between trial types partition results.

Since the eight-level ANOVA consisted of between-condition terms, the error term used in the contrasts testing RT and ER predictions is larger than actually necessary for proper statistical procedure. Thus, these tests will be conservative.

One-way ANOVAs indicated trial types to be significantly different for both RT and ER measures (Table 3, Appendix B). A series of contrasts (Winer, 1971) were made to test predictions from the Information Integration model. The RT prediction for the A condition $RT_s \approx RT_m < RT_i$ was upheld ($256 \approx 268 < 330$: where "$\approx$" is to be read as "not significantly different from"), as was the RT prediction for the AV condition $RT_s \approx RT_m < RT_i < RT_c$ ($338 \approx 347 < 414 < 489$). The ER predictions from the Information Integration model for both conditions were also supported, $ER_s \approx ER_m < ER_i$ ($.0104 \approx .0111 < .0475$) and $ER_s \approx ER_m < ER_i < ER_c$ ($.0167 \approx .0085 < .0260 < .01330$) (Table 4, Appendix B).

The graphed mean RTs and ERs are shown by condition in Figures 4 and 5. Notice the consistent difference in RT between the A and AV conditions for each common trial type and the striking consistency of the RT increase from S to I trial types in both the A and AV conditions;

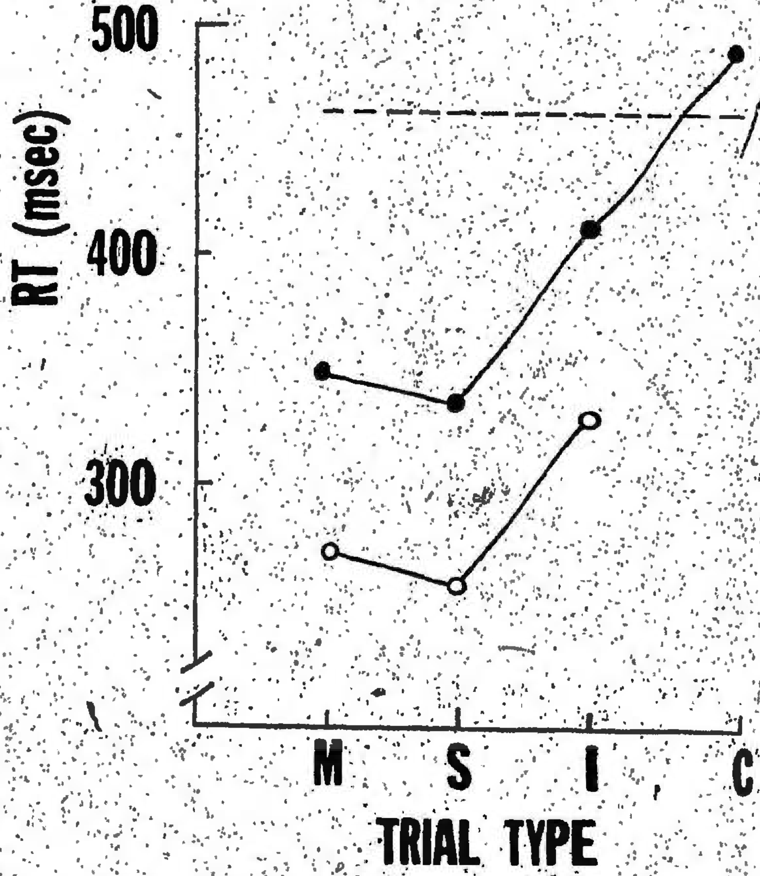

Figure 4

Between trial types graph of RT data by condition. AV-condition data is designated by filled circles, A-condition data by open circles, and the V-condition data by the dashed line.

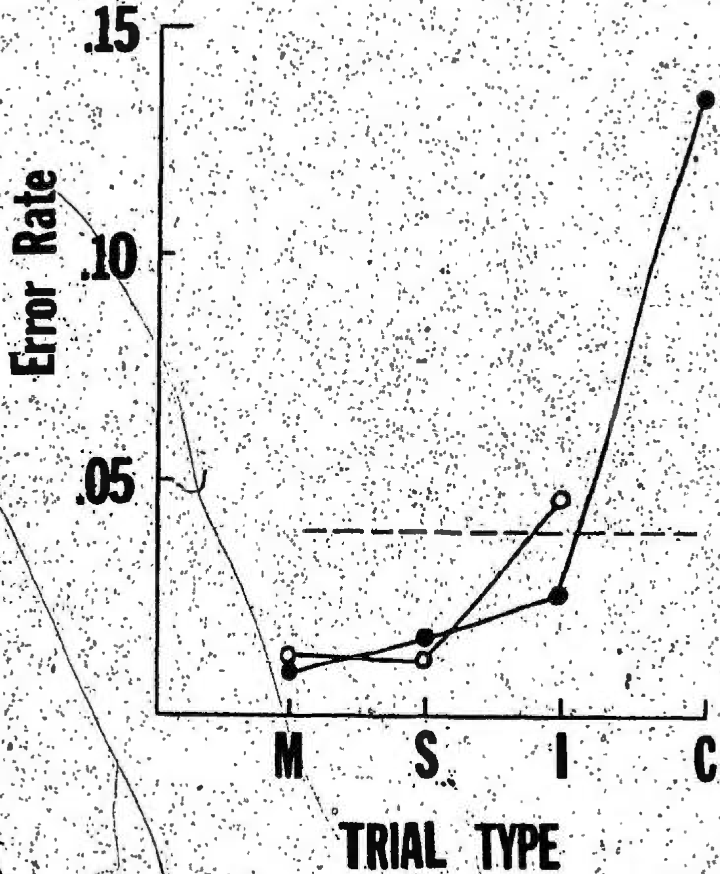

Figure 5

Between trial types graph of ER data by condition. AV-condition data is designated by filled circles, A-condition data by open circles, and V-condition data by the dashed line.

which continues to the @ trial type RT in the AV condition.

Between ears/ within condition partition results.

A condition. A 2 x 6 x 4 x 2 x 2 x 2 ANOVA (Factors: Hand, Subject (within Hand), Day, Letter, Trial Type, and Ear) indicated significant main effects of Day, Trial Type, and Ear, and a significant third-order interaction between Hand, Letter, Trial Type, and Ear (Table 5, Appendix B). The practice (Day) effect is a usual result of experiments which extend beyond one session and was not a surprising result. The main effect of Trial Type follows from the between trial types partition finding $RT_m < RT_i$ with a more conservative error term. The main effect of Ear was in the anticipated direction; letters presented to the dominant (right) ear were responded to more quickly than letters presented to the non-dominant ear (276 < 323 msec).

The third-order interaction is the most informative effect found in this partition as it provides the data to test the predictions $RT_{ma} < RT_{md}$ made by the Information Integration model and the stimulus-response compatibility argument; the Information Integration model prediction $RT_{id} < RT_{ia}$ is also tested within this partition. The RTs for both predictions were in the expected directions ($RT_{ma} = 256$, $RT_{md} = 286$, $RT_{id} = 331$, and $RT_{ia} = 339$ msec), but due to the confounding effects of dominant hand and ear, the RT values were not used in the associated contrasts. By taking the trial type subgroup means and collapsing over letters to eliminate the hand group difference between letters, then subtracting one ear value from the other (right-ear RT subtracted from left-ear RT), followed by subtracting the right-hand response term from the left-hand response term, an unbiased vector term for the interaction was derived (see Table 6, Appendix B). Note: the vector term would be positive when ear-hand correspondence was facilitory (eg. $RT_{ma} < RT_{md}$), and negative when ear-hand correspondence was impeding (eg. $RT_{id} < RT_{ia}$), independent of ear or hand bias. A set of contrasts were performed on the resultant vectors using an error term derived from the variance of each trial type. The vectors supported both predictions in direction; the contrast associated with the prediction $RT_{ma} < RT_{md}$ was highly significant, and the contrast associated with the prediction $RT_{id} < RT_{ia}$ was marginally significant (Table 6, Appendix B). The RTs from this interaction, pooled over letter, are graphed together with the values from the AV condition in Figure 6.

It was mentioned above that the Information Integration model should predict $ER_{id} < ER_{ia}$ (since IA trials are the only trials predicted to produce motor control unit reprograming). Of the 73 errors made in response to I trial types, 37 were on IA trials and 36 on ID trials; certainly this cannot be construed to indicate the model's assumption was correct. However, a <u>post-hoc</u> analysis of incorrect response RTs revealed the I trial types to be rather special cases. Where errors made in response to S and M trial types were generally lower in RT than correct responses ($90 < 256$ and $165 < 268$ msec, respectively), supporting the model assumption that errors are premature response enactments, I trial type errors were

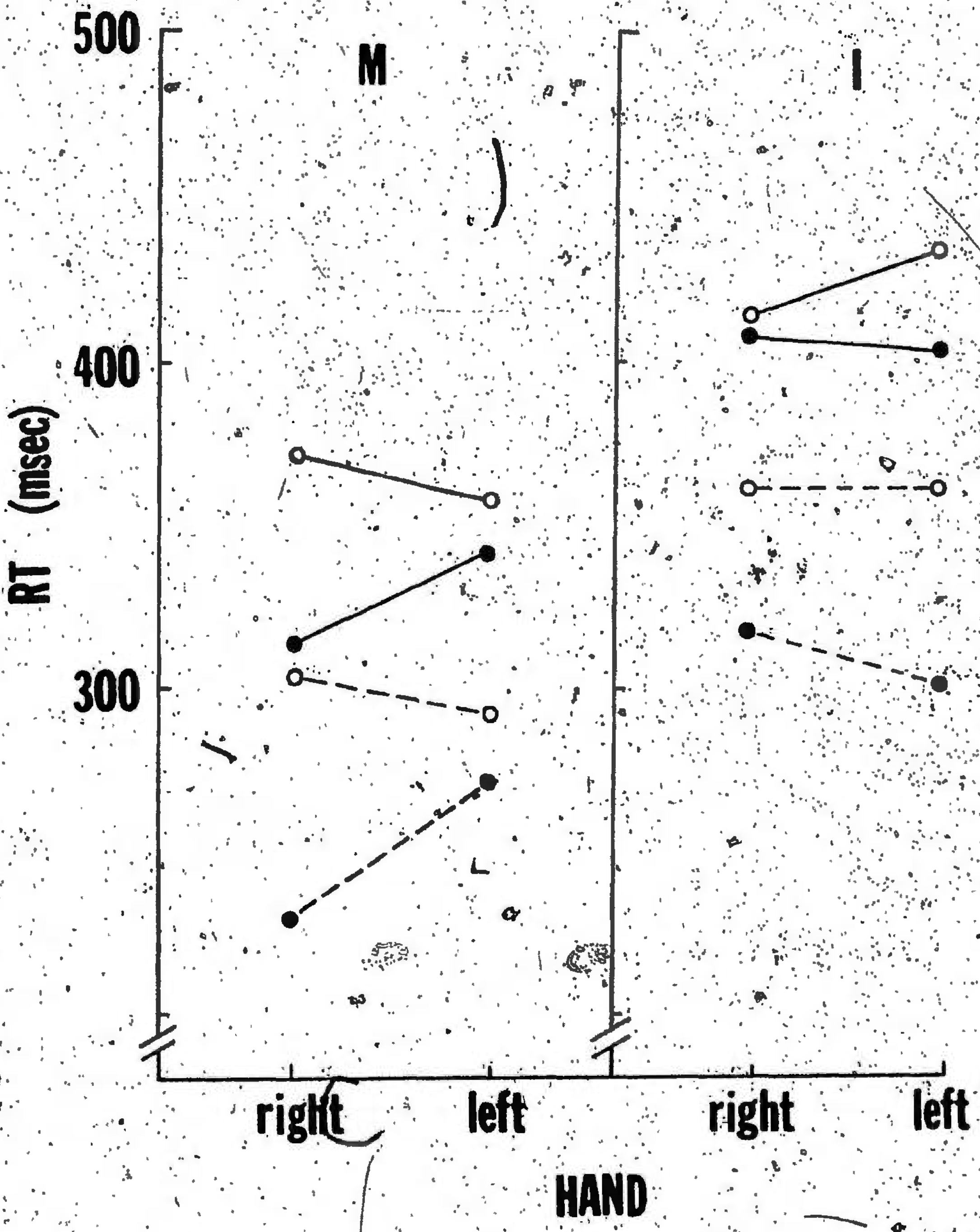

Figure 6

Graph of RTs by condition (AV and A represented by solid and dashed lines), ear of correct letter presentation (right and left represented by filled and open circles), and responding hand.

made somewhat slower than correct responses (350 > 330 msec). This pattern is consonant with the notion that a fruitless feature analysis disrupts processing when the analyzed feature is expected to occur within the input sampled. This would explain the slower RT, but the genesis of errors for the ID trials is not clear.

<u>AV condition</u>. A 2 x 6 x 4 x 2 x 3 x 2 ANOVA (Factors: Hand, Subject (within Hand), Day, Letter, Trial Type, and Ear) indicated significant main effects of Day and Trial Type; also significant were the interactions between Hand and Letter, Letter and Trial Type, Hand, Day, Letter, and Trial Type, Hand, Day, Trial Type, and Ear, and Hand, Letter, Trial Type, and Ear (Table 7, Appendix B). The main effects of Day and Trial Type are similar to those found for the A condition of this partition and the AV condition of the <u>between trial types</u> partition. This analysis did not find a significant Ear effect; perhaps the right-ear superiority washes out at higher RTs, or the presence of the visual stimulus lessens the Ear effect.

The first-order interaction between Hand and Letter was expected to occur as a manifestation of the counterbalancing of hand groups, i.e. right-hand responses should be made more quickly than left-hand responses; that this interaction was not significant in the A-condition analysis may indicate that with only auditory stimuli the Ear effects overshadow the Hand effects. The other first-order interaction, between Letter and Trial Type, seems to be a sampling error. RT was 30 msec slower when "A" responses were made to C trial types, while "A" responses were made faster than "E" responses to M and I trial types by only 7 and 4 msec, respectively.

The third-order interactions involving the Day factor are very difficult to interpret because of the large number of cells contained in them (48 each). These will not be discussed. The third-order interaction between Hand, Letter, Trial Type, and Ear showed $RT_{ma} < RT_{md}$ and $RT_{id} < RT_{ia}$ (335 < 360 and 409 < 420 msec), as predicted. Following the subtractive procedure described in the A-condition section of this partition, the AV-condition vectors were contrasted. The vectors were found to be of significant magnitude in the anticipated directions (Table 6, Appendix B). The AV-condition RTs, pooled over Letter, are graphed along with the A-condition RTs in Figure 6.

The ER data for the I trial types were again subjected to <u>post-hoc</u> consideration. The 40 errors in response to I trial types were again almost equally divided between IA (19) and ID (21) trials. The mean RTs for errors in response to the S, M, I, and C trial types were 218, 154, 315, and 285 msec, respectively. Error RTs were found to be lower for all trial types, including the I trial types. The differences between correct and incorrect RTs were 120 (S), 193 (M), 99 (I), and 204 (C) msec. These results again support the Information Integration model assumption that errors are premature response enactments. The I trial type RT difference is the smallest of the correct-incorrect RT differences and, since the AV condition evoked larger RTs than did the A condition, it might be suggested that if the critical feature is not found in an initial analysis of a given input usually containing that feature, a recursive search routine is begun. That the RT increment found in the I trial types error RT is not due to motor control unit reprograming is supported by the fact that C trial types produce an error RT of only 285 msec, less than the error RT of the I trial types. Of course, this compromises the comparison between the Information Integration model and the Energy Integration model predictions since the irrelevant stimulus seems to be treated as an information source, but it also means the auditory input is analyzed for quality when the visual stimulus must be considered the more critical input modality. Thus, the original contention which begat the Information Integration model, that all inputs are analyzed for content, is upheld by these results.

Within conditions partition results.

V condition. A 2 x 6 x 4 x 2 ANOVA (Factors: Hand, Subject (within Hand), Day, and Letter) indicated a significant main effect of Letter; no other significant effects were indicated (Table 8, Appendix B). The lack of a significant practice effect of Hand and Letter interaction was surprising, though the relatively small number of V condition trials per day (16) may not have been sufficient to stabilize the RT measure. The significant Letter effect, "A" responses were made more quickly than "E" responses ($455 < 475$), is similar to the Letter and Trial Type interaction found in the AV condition of the between ears/ within condition partition and indicates that the subjects in this experiment were faster in responding to the "A" stimulus when visual presentation was used.

A condition. A 2 x 6 x 4 x 2 x 3 ANOVA (Factors: Hand, Subject (within Hand), Day, Letter, and Trial Type) indicated significant main effects of Day and Trial Type; no other effects were significant (Table 9, Appendix B). These results confirm the ANOVA reported for the A condition in the between ears/ within condition partition and show that the inclusion of the S trial type RTs does not change the pattern of results.

AV condition. A 2 x 6 x 4 x 2 x 4 ANOVA (Factors: Hand, Subject (within Hand), Day, Letter, and Trial Type) indicated significant main effects of Day and Trial Type, and a third-order interaction between Hand, Day, Letter, and Trial Type (Table 10, Appendix B). These are the same results found in the between ears/ within condition ANOVA for the AV condition, showing that the S trial type RTs do not alter the pattern of results.

Experiment II

An objection to the foregoing experiment (Experiment I) might be raised on the basis that the letter "O" is too similar to the letters "A" and "E" to be an effectively "irrelevant" stimulus (since all are letters -- and vowels). This point would seem bolstered by the error RT data: since errors were generally slower responses for I trial types when compared to error RTs for the other trial types. If the "O" stimulus were to cause confusion, RT_i would be expected to increase as a result of a decrease in stimulus discriminability (Garner and Morton, 1969; Norman and Bobrow, 1975), biasing comparisons of RT_i with RT_m in favor of the Information Integration model predictions. For this reason a second experiment was run using a 1000 hz tone as the irrelevant stimulus. If the "O" stimulus was a cause of confusion, the resultant RT pattern should be different than the RT pattern of Experiment I; if the I trial type correct and error RTs retain the same relative position in the RT pattern, the "fruitless search" interpretation made above would gain support.

Method

The apparatus, design, and procedure of Experiment II were basically the same as in Experiment I with the exceptions that six subjects ran for two days, serving one and one-half hours the first day (the first half hour was devoted to practice) and one hour the second day.

Stimuli. The letter "O" was assigned the role of a warning signal, while the 1000 hz tone became the irrelevant stimulus. New tapes were made using the original four stimuli, by the same procedure as before. However, only seven trials of each trial type subgroup were used (instead of eight). The visual stimuli were the same as used in Experiment I. Presentation times and stimulus intensities were not changed between experiments.

Subjects. Six university students (3 male) volunteered to serve as subjects. All were paid two dollars an hour, all were right handed, and none had an uncorrected seeing or hearing deficit.

Results

Data analysis was done in the same manner as in Experiment I within the constraints of this experiment, eg. decreased trial type subgroup elements, subjects, days, and length of practice session. The same partitioning of data and ER and RT analyses were used.

Between conditions partition results.

The mean RTs for the A, AV, and V conditions were higher than in Experiment I: 422, 529, and 520 msec respectively. A one-way ANOVA indicated the between condition RTs were significantly different (Table 1, Appendix C). The predictions from the Information Integration model were again tested with an error term from a one-way ANOVA performed after the C trial type RTs were removed. The predictions $RT_A < RT_{AV}$ and $RT_A < RT_V$ were confirmed by a Dunnett's test using the A condition as the control condition. This replicated the results of Experiment I.

The ERs for the A, AV, and V conditions were .0276, .0342, and .0185 respectively. Both the AV and V condition ERs were quite a bit lower in this experiment. Removing the C trial types from the AV condition lowered ER_{AV} to .0180. A one-way ANOVA run with the C trial types removed from the AV condition indicated no significant difference between the conditions (Table 2, Appendix C). A Dunnett's test failed to show a significant difference between ER_A (.0276) and ER_{AV} (.0180), though the difference was in the direction predicted by the Information Integration model.

Between trial types partition results.

The between trial types RTs and ERs are graphed by condition in

Figures 7 and 8. A one-way ANOVA indicated both measures produced significant differences between trial types (Table 3, Appendix C). A series of contrasts showed the Information Integration model predictions of RT relationships to be supported in the A condition ($RT_s \approx RT_m < RT_i$: $406 \approx 398 < 463$ msec) and partially supported in the AV condition ($RT_s \approx RT_m < RT_i < RT_c$: $502 \approx 513 \approx 535 < 566$ msec). The contrasts are reported in Table 4, Appendix C.

The ER predictions from the Information Integration model likewise were fully supported in the A condition ($ER_s \approx ER_m < ER_i$: $.0000 \approx .0149 < .0536$) and partially supported in the AV condition ($ER_s \approx ER_m < ER_i < ER_c$: $.0060 \approx .0238 \approx .0179 < .0744$). These contrasts are reported in Table 4, Appendix C.

Between ears/ within conditions partition results.

A condition. A 2 x 3 x 2 x 2 x 2 x 2 ANOVA (Factors: Hand, Subject (within Hand), Day, Letter, Trial Type, and Ear) indicated significant main effects of Day and Trial Type and a first-order interaction between Letter and Trial Type (Table 5, Appendix C). The two main effects were expected and replicate effects found in Experiment I. The interaction between Letter and Trial Type results from the I and M trial types being more differentiated for "E" responses ($398 < 496$) then for "A" responses ($419 < 429$); the reason for this differentiation is not understood.

Surprisingly absent was a significant main effect of Ear and a significant third-order interaction between Hand, Letter, Trial Type, and Ear. This might have occurred if one or more of the (right-handed)

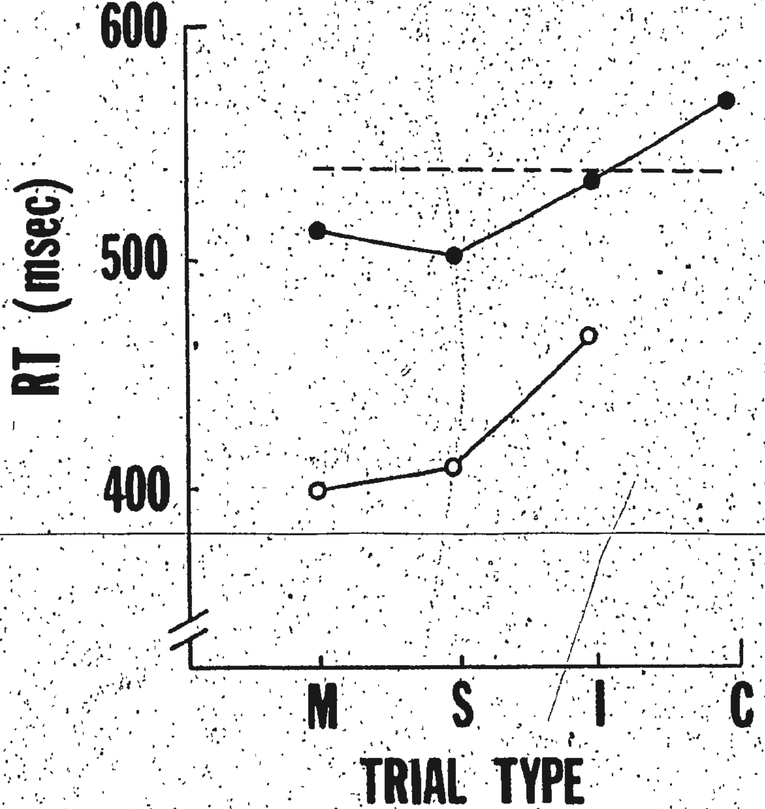

Figure 7

Between trial types graph of RT data by condition. AV-condition data is designated by filled circles, A-condition data by open circles, and V-condition data by the dashed line.

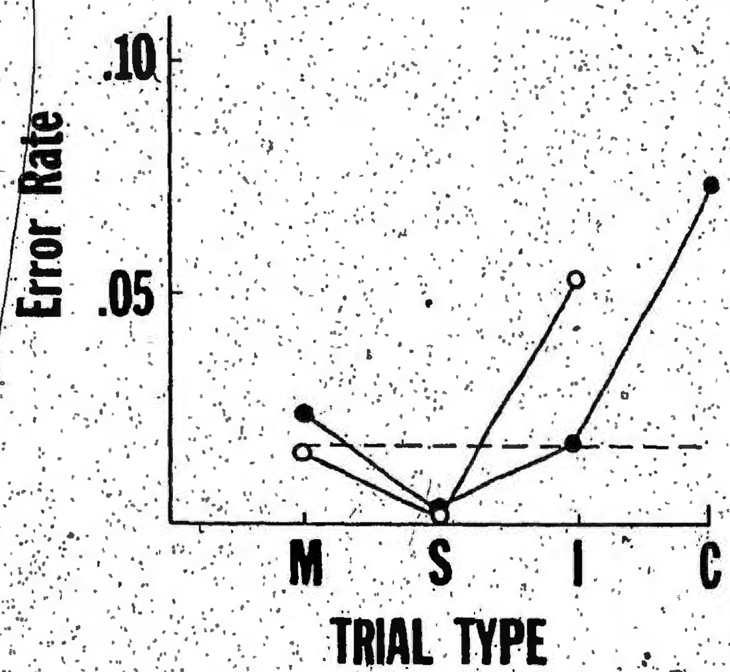

Figure 8

Between trial types graph of ER data by condition. AV-condition data is designated by filled circles, A-condition data by open circles, and V-condition data by the dashed line.

subjects were not left-hemisphere language dominant (see Kimura, 1966; Studdert-Kennedy and Shankweiler, 1970; Zangwill, 1960), if one or more subjects had an undetected right-ear hearing deficincy, or if hand preferences overshadowed ear preferences. The last possibility is the most likely since the interaction between Hand and Ear was marginally significant; also the RTs found here are of the same magnitude as the RTs found in the AV condition of Experiment I, it was suggested the lack of a significant Ear effect on RT_{AV} of Experiment I might have occurred due to a washout of ear effects at higher RTs, the right-ear superiority effect may be susceptible to short time limitations within the task employed by this study.

The interaction between Hand, Letter, Trial Type, and Ear was marginally significant; the cell RTs from this interaction, pooled over Letter, are graphed in Figure 9 with the corresponding RTs from the AV condition. Although the interaction term was not significant, the interaction was clearly in the predicted direction. The contrasts associated with the predictions $RT_{ma} < RT_{md}$ and $RT_{id} < RT_{ia}$ were tested after converting the RTs to vectors as in Experiment I. The contrasts showed both predictions to be accurrate (Table 6, Appendix C).

The ER prediction $ER_{id} < ER_{ia}$ was again considered <u>post-hoc</u>. Again, no evidence supporting the prediction was found: errors were evenly divided between the IA and ID trials. Unfortunately, the error RTs were, in fact, discarded and therefore could not be assessed as had the error RTs of Experiment I.

<u>AV condition</u>. A 2 x 3 x 2 x 2 x 3 x 2 ANOVA (Factors: Hand, Subject (within Hand), Day, Letter, Trial Type, and Ear) indicated

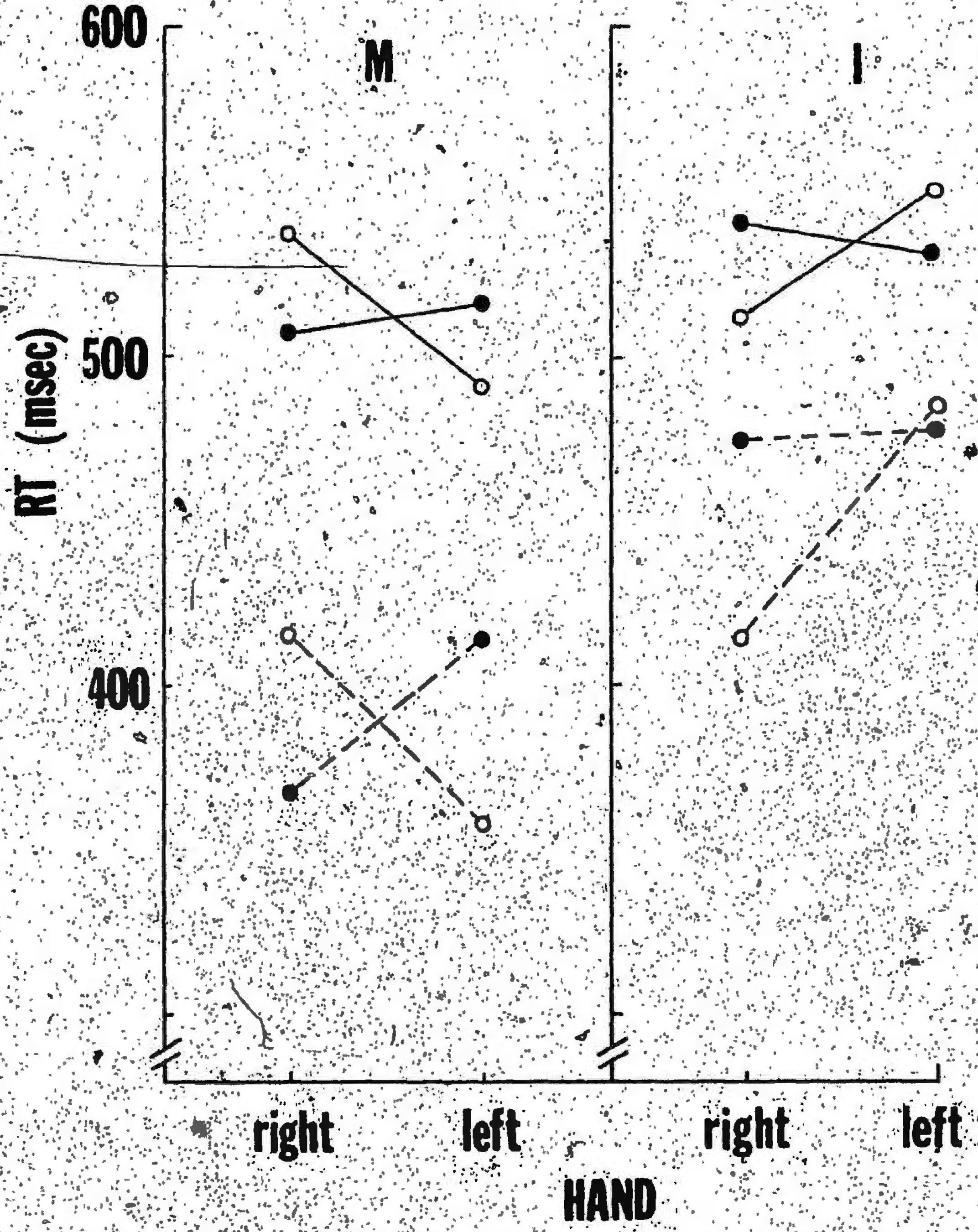

Figure 8

Graph of RTs by condition (AV and A represented by solid and dashed lines), ear of correct letter presentation (right and left represented by filled and open circles), and responding hand.

significant main effects of Day and Trial Type, a first-order interaction between Day and Trial Type, and a third-order interaction between Hand, Letter, Trial Type, and Ear (Table 7, Appendix C). As in the A condition, the ear of letter presentation was not a significant effect, but it had not been in the AV condition of Experiment I either; again, this suggests that the ear superiority effect washes out at higher RT values within the constraints of this experiment.

The interaction between Day and Trial Type seems to indicate a greater daily decrement in RT magnitude for the M and I trial types (about 62 msec) than for the C trial type (37 msec). This pattern also occurred in Experiment I with M and I trial type RTs decreasing by about 88 msec over the four days while the C trial type RT only decreased by 43 msec. However, in Experiment I this interaction was not significant.

The interaction between Hand, Letter, Trial Type, and Ear was treated subtractively as described in the <u>between ears/ within conditions</u> partition for the A condition of Experiment I. The vectors associated with the predictions $RT_{ma} < RT_{md}$ and $RT_{id} < RT_{ia}$ were found to be significantly different in the predicted directions (Table 6, Appendix C). A graph of the RTs associated with this interaction, pooled over Letter, is presented in Figure 9.

<u>Within conditions partition results</u>.

<u>V condition</u>. A 2 x 3 x 2 x 2 ANOVA (Factors: Hand, Subject (within Hand), Day, and Letter) indicated a significant interaction between Hand and Day (Table 8, Appendix C). The subjects responding to "A" with their right hand decreased RT_V by 35 msec over the two days,

while subjects responding to the letter "A" with their left hand increased RT_V by 23 msec. It is not apparent why this occurred.

A condition. A 2 x 3 x 2 x 2 x 3 ANOVA (Factors: Hand, Subject (within Hand), Day, Letter, and Trial Type) indicated significant main effects of Day and Trial Type, and a first-order interaction between Letter and Trial Type (Table 9, Appendix C). These were the same significant effects indicated by the between ears/ within conditions partition ANOVA; the inclusion of S trial type RTs did not alter the ANOVA results.

AV condition. A 2 x 3 x 2 x 2 x 4 ANOVA (Factors: Hand, Subject (within Hand), Day, Letter, and Trial Type) indicated main effects of Day and Trial Type to be significant (Table 10, Appendix C). These effects were found in the between ears/ within conditions partition ANOVA and were not changed by the inclusion of S trial type RTs. However, the S trial type RT inclusion acted to relegate the interaction between Day and Trial Type to marginal significance, indicating that the S trial trial type RTs did not decrease over days as many msec as did the M and I trial types ($35 < 63$ msec).

Discussion

The Information Integration model is obviously a more general model of stimulus processing than either the Energy Integration model or stimulus-response compatibility interpretations. It offers more predictions, and, on the basis of the results reported above, is more accurate then the Energy Integration model.

The Information Integration model leads to 17 predictions of RT and ER relationships for each of the two experiments. Of the 26 tested difference predictions, 25 were in the predicted direction; 22 were significant beyond the .05 level; one was marginally significant at the .1 level; and three were not significant. The one relationship in the opposite direction ($ER_m < ER_i$ in the AV condition of Experiment II) was not significantly so, and and may be attributed to the generally low error rate found in Experiment II. Of the eight predicted equivalences, no significant differences were found. Thus the Information Integration model led to 34 relationship predictions of which 30 (88%) were statistically accurate, and none of which were statistically in the wrong direction.

The Energy Integration model did not lead to accurate predictions in the experiments. It produced seven relational predictions for each experiment. Of the eight tested difference predictions, two were in the expected direction: both were significant, and both were also predicted by the Information Integration model. Of the six tested equivalence predictions, one was accurate ($RT_s \approx RT_i$ in the AV condition of Experiment II). Interestingly, this prediction was in opposition to the

Information Integration model prediction ($RT_s < RT_i$). Although the difference was in the direction predicted by the Information Integration model ($RT_s = 502$, $RT_i = 535$ msec), it was not significant. The Energy Integration model led to 14 predictions of which three (21%) were accurate, a record far inferior to that of the Information Integration model. Moreover, in the twelve cases where the two models were opposed, the Energy Integration model was supported only once while the Information Integration model was supported eleven times.

The stimulus-response compatability interpretation predictions were 100% accurate. However, there were only four predictions per experiment and they were also made by the Information Integration model. As the Information Integration model incorporates notions of stimulus-response compatibility in its response selection stage, the law of generalizability would favor the Information Integration model.

Considering it a failure of the Information Integration model to provide accurate predictions for the data of Experiment II (three of the four predictive failures were for Experiment II results) ignores the fact that the model attributes errors to premature response enactments, and the ramifications following on that fact. This attribution leads to the operational assumption that a sufficiently high evocation criterion would lower error rates to the extent that any between trial type variability of ER would be more a function of systemic variability than a function of processing method. Also, Experiment II resulted in higher RT values than Experiment I in all conditions for all trial types. This suggests that the subjects in Experiment II did in fact set higher evocation criterion values than did the subjects in Experiment I. Further, the Information Integration model attributes between trial type differences to decision time increases occurring due to response selection bottlenecks and motor control unit content changes. The effect of these increments would be reduced in the AV condition as the evocation criterion is raised. This reduction is assumed to occur because the visual input contained no contradicting features to cause bottlenecks and was a more effective response determinant due to the attenuation of auditory inputs by the frequency attenuator. All trial type RT differentiation in the AV condition is considered an effect of the auditory input; hence the AV condition would be predicted to produce less differentiation between trial type RTs as the evocation criterion is raised (the visual input is assumed to arrive at the central processor later than the auditory input). Moreover, the differentiation of A condition trial type RTs would not be expected to be influenced by evocation criterion changes since the auditory inputs cannot be distinguished by trial type or block type and differentially passed by the frequency attenuator. This leads to the prediction that with an increase in the evocation criterion the differentiation of AV condition trial type RTs will be diminished while the differentiation of A condition trial type RTs will be relatively unaffected. An inspection of Figures 4 and 7 shows this analysis to be accurate, the difference between M and I trial type RTs was 60 msec for the A condition and 67 msec for the AV condition in Experiment I, and was 65 msec for the A condition and 22 msec for the AV condition in Experiment II.

A second way a slowing down of responses might be considered is as a lengthening of the sample time. However, though a sampling time change would be predicted to decrease ER and increase RT, both alterations would be expected to occur together in both conditions. As the A condition RT increased while ER remained the same from Experiment I to Experiment II, the argument above in terms of an evocation criterion change seems more in agreement with the data (an increase in the evocation criterion would not be expected to decrease the A condition ER since the features used in determining the programing of the motor control unit would not change). Sample time logically seems more of a system-limited (process-limited) parameter of processing than does the evocation criterion. That is, sample time, in the Information Integration model, would be more affected by post-stimulation bottlenecking of information at the feature analyzer stage or by physiological variables than by pretrial volitional processes, whereas the evocation criterion would seem more affected by pretrial decisions -- probably the subject's consideration of the speed-accuracy tradeoff.

The only modification of the Information Integration model necessitated by the experimental results is the postulation of a recursive search by the feature analyzer for the task-critical feature when an input usually carrying that feature is analyzed and the feature is not found. This internal system "double-checking" is logically sound, and introspectively accurate. The increased RT found for I trial types, coupled with the lack of ER difference between the IA and ID trials, seems to indicate that instead of the implicit information in IA trials causing the motor control unit to be reprogramed, a double-checking process is begun. Assuming that any time a response selection does not match the contents of the motor control unit the feature(s) determining that selection are retested, IA trials (and C trial types) would consume more time than ID trials. If the response selection was tested to be certain that it was determined by the critical feature before being enacted (at the motor control unit), the processing system would better control the motor control unit program. If the test shows the response selection was determined by the critical feature, the motor control unit would be reprogramed in the case of a mismatch (C trial types) and/or the next sample taken. If the response selection was not determined by the critical feature (I trial types), another analysis is made of the input trace to be sure the critical feature had not been missed. For I trial types this last analysis would return the same result. It is assumed that the motor control unit is then reprogramed with the pretrial, "anticipatory" response, increasing I trial type RT and increasing the liklihood of errors equally for IA and ID trials. Thus, for the A condition correct and error RT would be expected to be of about the same magnitude, while for the AV condition correct responses would more often be determined by the visual input and therefore slower than the error responses. Errors might also result from a secondary search of decaying input data, making responses to I trial types somewhat risky ventures. The Information Integration model would predict a lower evocation criterion to result in the A condition if the I trial types were removed.

Redundancy effects in the Information Integration model.

The Information Integration model assumption that the amount of information available from all stimuli which maps onto the task requirements will affect performance was well demonstrated by the present experiments. The assumption that information might be in terms of symbols (eg. letter identity) or in implicit terms (eg. presentation location) was also corroborated by the experimental results. These effects might be viewed as evolving from basic stimulus redundancy effects: the more task-relevant information which indicates the same response, the more efficiently the response can be made (Garner, 1962). Of course, redundancy effects alone cannot explain the equivalence of RTs to S and M trial types, or quicker responses to M trial types than I trial types, but a redundancy interpretation is compatible with the findings that MA trials were responded to more quickly than MD trials, and ID trials were responded to more quickly than IA trials.

The advantages of considering redundancy effects within the context of the Information Integration model is the allowance of the model for interactions between different redundant elements, and the concomitant allowance for the superiority of one information source or feature over others. For example, in the response selection stage of the model where features are critical, letter identity will outweigh the correspondence (or non-correspondence) between response and stimulus location in the determination of response selection, although location correspondence is still considered able to affect the speed of response selection. Moreover, in the Information Integration model schema intensity is treated as a redundant feature of two stimuli which occur in close temporal proximity, so that, in the present experiments, the model maintained predictive accuracy while encompassing three redundant features.

Suggestions for further exploration of the Information Integration model.

Several aspects of the Information Integration model might be more explicitly tested. While the present experiments seem to establish some modicum of validity for the model, several other predictions can be generated from the model which test the evocation criterion and specific feature analyzer assumptions more specifically.

If the decision criterion was whether one instance or two of some feature occurred, the Information Integration model would predict responses to the single instance to be made more quickly than responses to the double instance since a bottleneck at the relevant feature analyzer would be expected to occur. Ostensibly this proposal is similar in kind to psychological refractory period experiments which find that if both the warning signal and reaction stimulus are presented in the same modality (eg. both are visual stimuli), RT is greater than if the stimuli are presented in separate modalities (Bertelson and Tisseyre, 1969; Davis and Green, 1969). These experiments show the feature analyzer assumption may be accurate, at least when modality is considered to be the critical feature. A more salient testing of feature analyzer assumptions might use letter identity as the decision criterion with the two-instance trials incorporating one auditory and one visual letter. By using both dual and single modality trials in a choice task, the influence of modality might be partialled out, and by using an irrelevant stimulus in one or the other stimulus position for some portion of the trials (or presenting catch-trials of one instance of each choice), the effect of feature repetition might be partialled out for measurement.

A second experiment suggested by the Information Integration model is a test of the prediction that the A- and AV-condition RTs would be equalized if the two conditions were presented within the same trial block. Since the difference between RT_A and RT_{AV} found in the present experiments was predicted to occur due to an increased evocation criterion established by the subjects to avoid errors in response to C trial types, by including catch-trials composed of only irrelevant auditory stimuli and excluding C trial types, the two conditions might be presented within the same block of trials while the obvious subjective stategy of responding to the auditory stimuli alone might be obviated.

A third course to take might be to attempt to quantify some of the mechanisms postulated by the Information Integration model; for example, the time period required for motor control unit changes and/or response selection when symbolic and implicit information disagree. Perhaps sample rate or amount of frequency attenuation might be discerned by a clever experimenter. In any event these parameters of the model are accessible by subtractive methods (Sternberg, 1969), and, though many trials would have to be run, a simpler designed experiment than those presented here would allow a multivariate analysis of stabilized RT data.

Feature integration.

The results of the present experiments indicate that a subject's performance is not only affected by stimulus information about the decisional criterion but also by other stimulus features which overlap response-performance characteristics. This finding supports the notion that stimulus features are combined whenever they coincide with response features. The primary evidence for this support is: 1) the ear stimulated by auditory presentation in M trials was irrelevant to the task and yet affected performance, and 2) the ear stimulated by the irrelevant stimulus in I trials was also irrelevant to the task and also affected performance. These performance effects of stimulus features irrelevant to the decision criterion imply that whenever features of temporally proximal stimuli coincide with response features they are automatically integrated in the formation of the response. Hence, the general question asked by this thesis, "How do stimuli from different modalities interact to indicate a common concept?", is answered as follows: "When features from stimuli sensed by the different modalities are common to that concept they are automatically integrated by the processing system into the response appropriate to the concept."

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Table 1

Subject's instruction sheet

This experiment is called a choice reaction time task. On each trial you will be required to make a choice between two alternatives. In this case your choice is between two response levers. One lever is used to designate the letter A, and the other lever is used to designate the letter E. The dependent measures of this experiment are the speed and accuracy of your choice.

The stimuli used here are the letters A, E, and O. These stimuli will be presented to you visually (on the screen in front of you), and verbally (via the headphones). The visual presentations will be of A and E only, while O will be added to the verbal presentation repertoire (verbal pronunciation is ā, ē, and ō). The verbal presentations treat each ear as an individual output point; that is, you may hear different letters in each ear.

The experiment will last for five days. Each day will consist of three blocks of trials; each of these blocks will be a different sort of trial:

1) visual-only trials: a letter (A or E) will be projected onto the screen in front of you (16 trials a block);
2) audio-only trials: verbal letters will be presented via the headphones (80 trials a block);
3) audio-visual trials: both visual and auditory letters will be presented simultaneously (in some cases both A and E will be verbally presented, in this event that letter which corresponds to the visual letter is correct; 112 trials a block).

Each experimental day will consist of these three trial types. Reaction time will be measured from the onset of the stimulus (stimuli) until your choice is made. The experimenter will tell you which lever corresponds to which letter. Ask him any questions you might have.

Table 2

Order of condition presentation.

Subject Number	Experimental Day 1	2	3	4
1	AVB*	BAV	VBA	BVA
2	AVB	VBA	BAV	VAB
3	BAV	AVB	VBA	AVB
4	BAV	VBA	AVB	VAB
5	VBA	AVB	BAV	ABV
6	VBA	BAV	AVB	BVA
7	ABV	BVA	VAB	BAV
8	ABV	VAB	BVA	VBA
9	BVA	ABV	VAB	AVB
10	BVA	VAB	ABV	VBA
11	VAB	ABV	BVA	AVB
12	VAB	BVA	ABV	BAV

* A, V, and B represent the auditory, visual, and auditory-visual conditions, respectively.

Table 3

Order of tape presentation (refer to Table 2, Appendix A, for condition).

Subject Number	Experimental Day 1	2	3	4
1	1,1,4	2,3,4	2,3,2	1,3,4
2	2,2,3	3,1,4	4,1,1	4,3,2
3	2,3,4	1,2,4	3,1,4	2,3,1
4	1,4,3	1,3,2	3,4,2	2,1,4
5	3,4,1	3,1,2	3,2,4	4,1,2
6	4,3,2	1,4,2	1,3,4	2,1,3
7	3,2,2	4,3,1	1,4,1	3,2,4
8	4,1,1	4,2,3	2,2,3	3,4,1
9	4,3,4	2,2,1	4,3,3	1,2,1
10	3,4,3	2,1,1	4,4,3	1,2,2
11	2,2,2	4,4,3	1,1,1	3,4,3
12	1,1,1	3,4,3	2,2,2	4,4,3

Table 1.

Between conditions analysis of RT results.

I. Including the C trial types.

a) Analysis of variance.

Source	SS	df	MS	F-Ratio	p(F)
Methods	6873568	2	3436784	268.63	<.001
Error	15941259	1245	12793.95		
Total	22814827	1247			

b) Dunnet's test for planned comparisons.

Condition	$(RT - RT_A)/\sqrt{2(MS_{error})/n}$ = t	p(t)
AV	(397-285)/ 2(12793.95)/416 = 14.29	<.001
V	(465-285)/ 2(12793.95)/416 = 22.96	<.001

II. Excluding the C trial types.

a) Analysis of variance.

Source	SS	df	MS	F-Ratio	p(F)
Methods	5717536	2	2858768	286.17	<.001
Error	10529378	1053	9989.92		
Total	16246914	1055			

b) Dunnet's test for planned comparisons.

Condition	$(RT - RT_A)/\sqrt{2(MS_{error})/n}$ = t	p(t)
AV	(367-285)/ 2(9989.92)/352 = 10.89	<.001
V	(465-285)/ 2(9989.92)/352 = 23.90	<.001

Table 2

Between conditions analysis of ER results.

I. Analysis of variance.

Source	SS	df	MS	F-Ratio	p(F)
Methods	.957	2	.4785	21.257	<.001
Error	190.12	8445	.0225		
Total	191.077	8447			

II. Dunnet's test for planned comparisons.

Condition	$(ER - ER_A)/\sqrt{2(MS_{error})/n} = t$	p(t)
AV*	(.0172-.0255)/ 2(.0225)/2816 = 514.4	<.001

*C trial types are excluded from the AV condition.

Table 3

Between trial types analysis of variance for both RT and ER.

I. Analysis of variance for RT data.

Source	SS	df	MS	F-Ratio	p(F)
Methods	8762144	7	1251734	119.55	<.001
Error	14994016	1432	10471		
Total	23756160	1439			

II. Analysis of variance for ER data.

Source	SS	df	MS	F-Ratio	p(F)
Methods	15.16	7	2.166	58.25	<.001
Error	370.93	9976	.0372		
Total	386.09	9983			

Table 4

Contrasts of RT and ER predicted values.

I. Mean RT and ER by trial type.

trial type	V	S_A	I_A	M_A	S_{AV}	I_{AV}	M_{AV}	C_{AV}
mean RT	465	256	330	268	338	414	347	489
ER	.0404	.0104	.0475	.0111	.0169	.0260	.0085	.1330

II. Computational formulae.

a) For unequal cell sizes.

$$SS = \frac{c_1X_1 + c_2X_2}{\frac{c_1^2}{n_1} + \frac{c_2^2}{n_2}} \quad \text{and} \quad F = \frac{SS}{MS_{error}}$$

b) For equal cell sizes.

$$SS = \frac{c_1X_1 + c_2X_2}{\frac{c_1^2}{n_1} + \frac{c_2^2}{n_2}} \quad \text{and} \quad F = \frac{SS}{MS_{error}}$$

III. The contrasts.*

F-Ratios

contrast	condition	RT	ER
S – M	A	<1	<1
	AV	<1	<1
M – I	A	35.24***	27.35***
	AV	41.16***	6.32**
I – C	AV	231.78***	236.37***

*constants: for RT, $n_s = 96$, $n_{m,i,c} = 192$, $MS_{error} = 10471$;
for ER, $n_s = 768$, $n_{m,i,c} = 1536$, $MS_{error} = .0372$;
$c_1 = 1$, $c_2 = -1$.

** $p < .05$
*** $p < .001$

Table 5

Between ears/within condition ANOVA.

Source	Den.	df Num.	df Den	MS	F-Ratio	p(F)
Hand (H)	S	1	10	39577	.185	
Subjects (S)		10		213950		
Day (D)	SxD	3	30	160597	14.853	<.001
HxD	SxD	3	30	4287	.396	
SxD		30		10812		
Letter (L)	SxL	1	10	21555	4.035	<.1
HxL	SxL	1	10	1530	.286	
SxL		10		5343		
Trial Type (TT)	SxTT	1	10	368741	20.293	<.001
HxTT	SxTT	1	10	16154	.889	
SxTT		10		18171		
Ear (E)	SxE	1	10	217435	26.506	<.001
HxE	SxE	1	10	23	.003	
SxE		10		8203		
DxL	SxDxL	3	30	6768	2.068	
HxDxL	SxDxL	3	30	67	.021	
SxDxL		30		3272		
DxTT	SxDxTT	3	30	11173	2.786	<.1
HxDxTT	SxDxTT	3	30	3879	.967	
SxDxTT		30		4011		
DxE	SxDxE	3	30	512	.206	
HxDxE	SxDxE	3	30	1525	.613	
SxDxE		30		2489		
LxTT	SxLxTT	1	10	6706	1.256	
HxLxTT	SxLxTT	1	10	14137	2.648	
SxLxTT		10		5339		
LxE	SxLxE	1	10	16634	3.042	
HxLxE	SxLxE	1	10	7909	1.446	
SxLxE		10		5468		
DxLxTT	SxDxLxTT	3	30	5429	2.391	
HxDxLxTT	SxDxLxTT	3	30	638	.281	
SxDxLxTT		30		2271		

Table 5 (continued)

Source	Den.	df Num.	df Den.	MS	F-Ratio	p(F)
DxLxE	SxDxLxE	3	30	2063	1.166	
HxDxLxE	SxDxLxE	3	30	641	.362	
SxDxLxE		30		1770		
TTxE	SxTTxE	1	10	1189	.151	
HxTTxE	SxTTxE	1	10	13713	1.742	
SxTTxE		10		7871		
DxTTxE	SxDxTTxE	3	30	945	.371	
HxDxTTxE	SxDxTTxE	3	30	423	.166	
SxDxTTxE		30		2548		
LxTTxE	SxLxTTxE	1	10	1634	.649	
HxLxTTxE	SxLxTTxE	1	10	27772	11.025	<.01
SxLxTTxE		10		2519		
DxLxTTxE	SxDxLxTTxE	3	30	666	.404	
HxDxLxTTxE	SxDxLxTTxE	3	30	1490	.904	
SxDxLxTTxE		30		1648		

Table 6

Between ears/within conditions contrasts of M and I trial types.

I. Means for A and AV conditions.

a) A condition.

TT*	H**	EAR L	EAR R	difference (L - R)
M	R	301	230	71
	L	291	272	19
		hand difference (R - L)		52
I	R	361	318	43
	L	361	302	59
		hand difference (R - L)		-16

b) AV condition.

TT	H	EAR L	EAR R	difference (L - R)
M	R	369	312	57
	L	357	351	6
		hand difference (R - L)		51
I	R	413	406	7
	L	433	404	29
		hand difference (R - L)		-22

II. Contrasts.

Cond.	TT	(n-1)V=SS	df	MS_{error}	F***	p(t)
A	M	2395347	381	6287	41.29	<.001
	I	6613644	381	17359	1.42	>.1
AV	M	3386486	381	8888	28.09	<.001
	I	4470759	381	11734	3.96	<.05

*Trial Type
**Hand
***$F = (n/4)(\text{hand difference})^2 / MS_{error}$; $n = 384$, df = n - 3

Table 7

Between ears/within conditions ANOVA, AV condition.

Source	Den	df Num	df Den	MS	F-Ratio	p(F)
Hand (H)	S	1	10	12407	.046	
Subjects (S)		10		266889		
Day (D)	SxD	3	30	129996	4.050	<.025
HxD	SxD	3	30	4844	.151	
SxD		30		32096		
Letter (L)	SxL	1	10	17277	4.123	<.1
HxL	SxL	1	10	29005	6.922	<.05
SxL		10		4191		
Trial Type (TT)	SxTT	2	20	968186	44.816	<.001
HxTT	SxTT	2	20	15722	.728	
SxTT		20		21604		
Ear (E)	SxE	1	10	75052	4.640	<.1
HxE	SxE	1	10	128	.008	
SxE		10		16175		
DxL	SxDxL	3	30	1086	.642	
HxDxL	SxDxL	3	30	1549	.916	
SxDxL		30		1690		
DxTT	SxDxTT	6	60	7447	1.970	
HxDxTT	SxDxTT	6	60	2731	.723	
SxDxTT		60		3779		
DxE	SxDxE	3	30	3270	.874	
HxDxE	SxDxE	3	30	2313	.618	
SxDxE		30		3743		
LxTT	SxLxTT	2	20	23992	3.639	<.05
HxLxTT	SxLxTT	2	20	1461	.222	
SxLxTT		20		6593		
LxE	SxLxE	1	10	43	.015	
HxLxE	SxLxE	1	10	2538	.885	
SxLxE		10		2869		
DxLxTT	SxDxLxTT	6	60	1216	.478	
HxDxLxTT	SxDxLxTT	6	60	6627	2.606	<.05
SxDxLxTT		60		2542		

Table 7 (continued)

Source	Den	df Num	df Den	MS	F-Ratio	p(F)
DxLxE	SxDxLxE	3	30	1935	.965	
HxDxLxE	SxDxLxE	3	30	20	.010	
SxDxLxE		30		2005		
TTxE	SxTTxE	2	20	2956	.309	
HxTTxE	SxTTxE	2	20	8416	.878	
SxTTxE		20		9580		
DxTTxE	SxDxTTxE	6	60	2708	.957	
HxDxTTxE	SxDxTTxE	6	60	10373	3.666	<.005
SxDxTTxE		60		2829		
LxTTxE	SxLxTTxE	2	20	2132	.543	
HxLxTTxE	SxLxTTxE	2	20	17566	4.471	<.025
SxLxTTxE		20		3929		
DxLxTTxE	SxDxTTxE	6	60	654	.482	
HxDxLxTTxE	SxDxTTxE	6	60	2243	1.654	
SxDxTTxE		60		1356		

Table 8

Within conditions ANOVA, V condition.

Source	Den	df Num	df Den	MS	F-Ratio	p(F)
Hand (H)	S	1	10	11956	.338	
Subject (S)		10		35407		
Day (D)	SxD	3	30	6477	2.245	<.1
HxD	SxD	3	30	2153	.746	
Letter (L)	SxL	1	10	10175	5.271	<.05
HxL	SxL	1	10	3282	1.700	
SxL		10		1930		
DxL	SxDxL	3	30	598	.777	
HxDxL	SxDxL	3	30	610	.792	
SxDxL		30		769		

Table 9

Within condition ANOVA, A condition.

Source	Den	df Num	df Den	MS	F-Ratio	p(F)
Hand (H)	S	1	10	65672	.228	
Subject (S)		10		288225		
Day (D)	SxD	3	30	250434	16.868	<.005
HxD	SxD	3	30	9325	.628	
SxD		30		14847		
Letter (L)	SxL	1	10	26266	2.788	
HxL	SxL	1	10	53	.006	
SxL		10		9420		
Trial Type (TT)	SxTT	2	20	301087	24.565	<.005
HxTT	SxTT	2	20	8239	.672	
DxL	SxDxL	3	30	9205	2.034	
HxDxL	SxDxL	3	30	1551	.343	
SxDxL		30		4524		
DxTT	SxDxTT	6	60	7198	2.176	
HxDxTT	SxDxTT	6	60	2721	.822	
SxDxTT		60		3309		
LxTT	SxLxTT	2	20	3669	.506	
HxLxTT	SxLxTT	2	20	10119	1.394	
SxLxTT		20		7257		
DxLxTT	SxDxLxTT	6	60	3811	1.658	
HxDxLxTT	SxDxLxTT	6	60	2569	1.118	
SxDxLxTT		60		2298		

Table 10

Within condition ANOVA, AV condition.

Source	Den	df Num	df Den	MS	F-Ratio	p(F)
Hand (H)	S	1	10	35385	.105	
Subject (S)		10		337830		
Day (D)	SxD	3	30	198675	4.320	<.025
HxD	SxD	3	30	15936	.347	
SxD		30		45986		
Letter (L)	SxL	1	10	325	.066	
HxL	SxL	1	10	32910	6.652	<.05
SxL		10		4947		
Trial Type (TT)	SxTT	3	30	939166	53.333	<.005
HxTT	SxTT	3	30	14031	.797	
SxTT		30		17610		
DxL	SxDxL	3	30	1559	.615	
HxDxL	SxDxL	3	30	4653	1.834	
SxDxL		30		2537		
DxTT	SxDxTT	9	90	6498	1.916	
HxDxTT	SxDxTT	9	90	5776	1.703	
SxDxTT		90		3391		
LxTT	SxLxTT	3	30	44839	7.942	<.01
HxLxTT	SxLxTT	3	30	1198	.212	
SxLxTT		30		5646		
DxLxTT	SxDxLxTT	9	90	871	.299	
HxDxLxTT	SxDxLxTT	9	90	9266	3.184	<.01
SxDxLxTT		90		2910		

Table 1

Between conditions analysis of RT results, Experiment II.

I. Including C trial types.

a) Analysis of variance.

Source	SS	df	MS	F-Ratio	p(F)
Methods	829488	2	414744	64.35	<.001
Error	1991569	309	6445		
Total	2821057	311			

b) Dunnett's test for planned comparisons.

Condition	$(RT - RT_A)/$	$2(MS_{error})/n$	$= t$	$p(t)$
AV	(529-422)/	2(6445)/120	= 10.32	<.005
V	(520-422)/	2(6445)/24	= 4.23	<.005

II. Excluding C trial types.

a) Analysis of variance.

Source	SS	df	MS	F-Ratio	p(F)
Methods	628680	2	314340	29.77	<.001
Error	1700233	161	10560		
Total	2322913	163			

b) Dunnett's test for planned comparisons.

Condition	$(RT - RT_A)/$	$\sqrt{2(MS_{error})/n}$	$= t$	$p(t)$
AV	(520-422)/	$\sqrt{2(10560)/120}$	= 7.38	<.005
A	(520-422)/	$\sqrt{2(10560)/24}$	= 3.30	<.005

Table 2

Between conditions analysis of ER results.

I. Analysis of variance.

Source	SS	df	MS	F-Ratio	p(F)
Methods	.0414	2	.0207	.954	
Error	40.054	1845	.0217		

II. Dunnett's test for planned comparisons.

Condition	$(ER - ER_A)/\sqrt{2(MS_{error})/n} = t$	p(t)
AV*	$(.0179-.0274)/\sqrt{2(.0217)/840} = 1.319$	<.1

*ER_{AV} does not include C trial types.

Table 3

Between trial types analysis of variance for both RT and FR.

I. Analysis of variance for RT data.

Source	SS	df	MS	F-Ratio	p(F)
Methods	1200128	7	171447	29.14	<.001
Error	2070848	352	5883		
Total	3270976	359			

II. Analysis of variance for FR data.

Source	SS	df	MS	F-Ratio	p(F)
Methods	1.26	7	.18	6.23	<.001
Error	62.78	2176	.0289		
Total	62.92	2183			

Table 4

Contrasts of RT and ER predicted values.

I. Mean RT and ER by trial type.

	Trial Type							
	A condition				AV condition			
	V	S	I	M	S	I	M	C
RT	520	406	463	398	502	535	513	566
ER	.0179	.0000	.0536	.0149	.0060	.0179	.0238	.0744

II. The contrasts[1]

contrast	condition	F-Ratios RT	F-Ratios ER
S - M	A	<1	2.33
	AV	<1	3.33
M - I	A	17.24**	8.71**
	AV	1.97	<1
I - C	AV	3.92*	18.56**

*p(F) .05
**p(F) .005

[1] constants: for RT, $n_s=24$, $n_{m,i,c}=48$, $MS_{error}=5883$
for ER, $n_s=168$, $n_{m,i,c}=336$, $MS_{error}=.0289$

Table 5

Between ears/ within condition ANOVA.

Source	Den	df Num	df Den	MS	F-Ratio	p(F)
Hand (H)	S	1	4	63	.007	
Subject (S)		4		87712		
Day (D)	SxD	1	4	125414	470.79	<.001
HxD	SxD	1	4	169	.633	
SxD		4		266		
Letter (L)	SxL	1	4	4185	.519	
HxL	SxL	1	4	1420	.176	
SxL		4		8062		
Trial Type (TT)	SxTT	1	4	99857	15.05	<.025
HxTT	SxTT	1	4	1880	.283	
SxTT		4		6633		
Ear (E)	SxE	1	4	865	.439	
HxE	SxE	1	4	10185	5.17	<.1
SxE		4		1972		
DxL	SxDxL	1	4	2935	1.144	
HxDxL	SxDxL	1	4	2342	.913	
SxDxL		4		2566		
DxTT	SxDxTT	1	4	1	.002	
HxLxTT	SxDxTT	1	4	1537	.365	
SxDxTT		4		4217		
DxE	SxDxE	1	4	1048	1.337	
HxDxE	SxDxE	1	4	22	.028	
SxDxE		4		784		
LxTT	SxLxTT	1	4	69060	18.03	<.025
HxLxTT	SxLxTT	1	4	21725	5.67	<.1
SxLxTT		4		3831		
LxE	SxLxE	1	4	9899	1.668	
HxLxE	SxLxE	1	4	8217	1.385	
SxLxE		4		5933		
DxLxTT	SxDxLxTT	1	4	192	.155	
HxDxLxTT	SxDxLxTT	1	4	2270	1.829	
SxDxLxTT		4		1241		

Table 5 (continued)

Source	Den	df Num	df Den	MS	F-Ratio	p(F)
DxLxE	SxDxLxE	1	4	899	.935	
HxDxLxE	SxDxLxE	1	4	2	.002	
SxDxLxE		4		962		
TTxE	SxTTxE	1	4	9623	1.497	
HxTTxE	SxTTxE	1	4	27197	4.230	
SxTTxE		4		6430		
DxTTxE	SxDxTTxE	1	4	3	.003	
HxDxTTxE	SxDxTTxE	1	4	2329	2.012	
SxDxTTxE		4		1158		
LxTTxE	SxLxTTxE	1	4	42	.004	
HxLxTTxE	SxLxTTxE	1	4	63286	5.78	<.1
SxLxTTxE		4		10958		
DxLxTTxE	SxDxLxTTxE	1	4	4093	1.085	
SxDxLxTTxE	SxDxLxTTxE	1	4	173	.046	
SxDxLxTTxE		4		3773		

Table 6

Between ears/ within condition contrasts of M and I trial types.

I. Means for the A and AV conditions.

a) A condition.

TT*	H**	EAR L	R	ear difference (L - R)
M	R	416	368	48
	L	359	415	-56
		hand difference (R - L)		104
I	R	414	473	-59
	L	485	478	7
		hand difference (R - L)		-66

b) AV condition.

TT	H	L	R	ear difference (L-R)
M	R	537	508	29
	L	491	516	-25
		hand difference (R - L)		54
I	R	510	539	-29
	L	550	532	18
		hand difference (R - L)		-47

II. The contrasts.

Cond.	TT	(n-1)V=SS	df	MS_{error}	F***	p(F)
A	M	742995	93	7989	32.49	.001
	I	1151210	93	12379	8.45	.001
AV	M	488110	93	5248	13.34	.001
	I	368695	93	3964	13.37	.001

* Trial Type
** Hand
*** $F = (n/4)(\text{hand difference})^2 / MS_{error}$; n = 96, df = n - 3

Table 7

Between ears/ within condition ANOVA, IV condition.

Source	Den	df Num	df Den	MS	F-Ratio	p(F)
Hand (H)	S	1	4	77632	2.235	
Subject (S)		4		34783		
Day (D)	SxD	1	4	103389	25.33	<.01
HxD	SxD	1	4	1203	.295	
SxD		4		4082		
Letter (L)	SxL	1	4	3525	1.747	
HxL	SxL	1	4	16	.008	
SxL		4		2018		
Trial Type (TT)	SxTT	2	8	34268	12.73	<.005
HxTT	SxTT	2	8	3291	1.222	
SxTT		8		2693		
Ear (E)	SxE	1	4	3188	.872	
HxE	SxE	1	4	3248	.888	
SxE		4		3655		
DxL	SxDxL	1	4	1812	1.575	
HxDxL	SxDxL	1	4	273	.238	
SxDxL		4		1150		
DxTT	SxDxTT	2	8	2933	6.41	<.025
HxDxTT	SxDxTT	2	8	1648	3.60	<.1
SxDxTT		8		457		
DxE	SxDxE	1	4	2079	.905	
HxDxE	SxDxE	1	4	722	.314	
SxDxE		4		2297		
LxTT	SxLxTT	2	8	254	.033	
HxLxTT	SxLxTT	2	8	4428	.584	
SxLxTT		8		7578		
LxE	SxLxE	1	4	24	.025	
HxLxE	SxLxE	1	4	1	.001	
SxLxE		4		961		
DxLxTT	SxDxLxTT	2	8	1259	.697	
HxDxLxTT	SxDxLxTT	2	8	1406	.778	
SxDxLxTT		8		1807		

Table 7 (continued)

Source	Den	df Num	df Den	MS	F-Ratio	p(F)
DxLxE	SxDxLxE	1	4	1054	.552	
HxDxLxE	SxDxLxE	1	4	2897	1.519	
SxDxLxE		4		1907		
TTxE	SxTTxE	2	8	2522	.981	
HxTTxE	SxTTxE	2	8	2059	.801	
SxTTxE		8		2569		
DxTTxE	SxDxTTxE	2	8	4381	2.810	
HxDxTTxE	SxDxTTxE	2	8	2122	1.361	
SxDxTTxE		8		1559		
LxTTxE	SxLxTTxE	2	8	925	1.181	
HxLxTTxE	SxLxTTxE	2	8	8067	10.30	<.01
SxLxTTxE		8		783		
DxLxTTxE	SxDxLxTTxE	2	8	932	.556	
HxDxLxTTxE	SxDxLxTTxE	2	8	619	.369	
SxDxLxTTxE		8		1678		

Table 8

Within condition ANOVA, V condition.

Source	Den df	Num df	Den	MS	F-Ratio	p(F)
Hand (H)	S	1	4	28739	5.36	<.1
Subject (S)		4		5360		
Day (D)	SxD	1	4	199	.318	
HxD	SxD	1	4	4935	7.89	<.05
SxD		4		626		
Letter (L)	SxL	1	4	19	.012	
HxL	SxL	1	4	1114	.666	
SxL		4		1672		
DxL	SxDxL	1	4	279	.212	
HxDxL	SxDxL	1	4	116	.089	
SxDxL		4		1314		

Table 9

Within condition ANOVA, A condition.

Source	Den	df Num	df Den	MS	F-Ratio	p(F)
Hand (H)	S	1	4	7185	.059	
Subject (S)		4		122650		
Day (D)	SxD	1	4	136150	146.38	<.001
HxD	SxD	1	4	3414	3.67	
SxD		4		930		
Letter (L)	SxL	1	4	1	.001	
HxL	SxL	1	4	0	.000	
SxL		4		14614		
Trial Type (TT)	SxTT	2	8	59800	16.14	<.005
HxTT	SxTT	2	8	6570	1.773	
SxTT		8		3706		
DxL	SxDxL	1	4	10796	2.361	
HxDxL	SxDxL	1	4	9639	2.108	
SxDxL		4		4573		
DxTT	SxDxTT	2	8	4192	1.214	
HxDxTT	SxDxTT	2	8	2578	.747	
SxDxTT		8		3453		
LxTT	SxLxTT	2	8	40643	9.63	<.01
HxLxTT	SxLxTT	2	8	12993	3.079	
SxLxTT		8		4220		
DxLxTT	SxDxLxTT	2	8	1506	1.943	
HxDxLxTT	SxDxLxTT	2	8	2649	3.42	<.1
SxDxLxTT		8		775		

Table 10

Within condition ANOVA, AV condition.

Source	Den	df Num	df Den	MS	F-Ratio	p(F)
Hand (H)	S	1	4	117093	2.688	
Subject (S)		4		43568		
Day (D)	SxD	1	4	113710	16.41	<.025
HxD	SxD	1	4	3219	.465	
SxD		4		6927		
Letter (L)	SxL	1	4	3124	.506	
HxL	SxL	1	4	105	.017	
SxL		4		6171		
Trial Type (TT)	SxTT	3	12	38330	14.74	<.001
HxTT	SxTT	3	12	2613	1.004	
SxTT		12		2601		
DxL	SxDxL	1	4	3241	2.059	
HxDxL	SxDxL	1	4	1677	1.065	
SxDxL		4		1574		
DxTT	SxDxTT	3	12	3116	3.03	<.1
HxDxTT	SxDxTT	3	12	1377	1.340	
SxDxTT		12		1028		
LxTT	SxLxTT	3	12	330	.053	
HxLxTT	SxLxTT	3	12	2984	.481	
SxLxTT		12		6200		
DxLxTT	SxDxLxTT	3	12	900	.656	
HxDxLxTT	SxDxLxTT	3	12	4544	3.31	<.1
SxDxLxTT		12		1371		