Temporal Order Judgments and Hemispheric Differences

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In the human neuropsychological research, the emphasis on time is not a new description of hemispheric function (see Ohgishi, 1977). The temporal factor of cerebral asymmetries has been investigated in three ways in laterality experiments. First, it is discussed in terms of human resource allocation systems, about which cognitive laterality experiments adopting time-sharing/dual-task paradigm have been reported (see Ohgishi, 1987, 1988a, 1988b). Second, this factor is related to the simultaneous-successive (or sequential) dichotomy discussed by Luria(1966) and to the temporal-spatial mechanisms of Lashley (1951). Since one of the important features of verbal material is its sequential character (Hirsh, 1967), it may be assumed that nonverbal but sequentially patterned sounds will be mediated by the left hemisphere. This leads to the idea that reliance upon time as a principle of behavioral organization distinguishes the left from the right cerebral hemisphere, that is, the left hemisphere is concerned with it whereas the right hemisphere is not.

Cohen (1973) advanced the hypothesis that the hemispheres would be differentially specialized such that the left hemisphere processes in a serial fashion (processing time increases with the number of elements to be processed), whereas the right hemisphere processes in a parallel fashion (processing time independent of the number of elements). Furthermore, Ohgishi (1977) compared upright and inverted Japanese letters and obtained increasing reaction times for left hemisphere presentations and generally flat functions for right hemisphere presentations only for the upright stimuli. This result fairly supported Cohen's hypothesis about the information-processing modes in the brain. Although Cohen limited this claim to alphanumeric stimuli, it seems now to be firmly fixed in the cognitive psychology in a stronger fashion, that is, the left and right hemispheres process all information in a serial and parallel mode respectively. Generally compatible with Cohen's research, Seamon and Gazzaniga (1973), have linked a subvocal rehearsal strategy to serial processing and a relational imagery strategy (combining target items in a single, interactive image) to parallel processing. Moreover, these authors hypothesized that the two types of coding processes represent hemispheric specializations and that the processes may be unilaterally localized.

Many investigators have the opinion that serial processing is also intimately linked to other functions that are labeled as temporal.

Third, both neuropsychological and cognitive studies have presented the evidence that processing of temporal information is the prototypical picture of left hemisphere mediation. These studies have usually employed the methodological paradigm of the temporal order judgment which were originally developed in visual and auditory perceptual experiments. In this article, studies that are relevant to the temporal order judgment are reviewed.

Nature of the Temporal Order Judgment

Accurate determination of the temporal ordering of events is of fundamental importance to the majority of perceptual abilities possessed by all living creatures. In spite of the importance of this attribute, however, much is not known about neither the degree to which such determinations can be made nor the mechanisms which underlie the process. Different types of subjects (right- or left-handed, adults or children) participating, the judgment of the correct order of two successive stimuli (either identical or nonidentical), presented to the same sensory modality or to two different modalities, have been investigated by many authors over the past 25 years (for example, Babkoff, 1975; Carmon & Nachshon, 1971; Efron, 1963a, b, c, 1973; Hirsh & Sherrick, 1961; May, Williams, & Dunlap, 1988; Oatley, Robertson, & Scanlan, 1969; Ohgishi, 1981; Robinson, 1967; Rutschmann, 1966, 1973; Rutschmann & Link, 1964; Sherwin & Efron, 1980; Swisher & Hirsh, 1972). Several general findings about the temporal order judgment have, by now, been verified by almost all of these authors.

The nature of successive stimuli is the difference between arrival times. In Allan, Kristofferson, and Wiens'(1971) attention-switching model, it is suggested that stimuli are judged as simultaneous or as successive depending on whether or not attention has switched fast enough to each of the relevant channels. This model assumes that information transmitted through different channels cannot enter the central processor at the same time since attention can be focused upon one channel at a time. Because of this central limitation, all information conveyed by nondominant channels is neglected until attention is switched to them.

On the contrary, Rutschmann (1973) suggests the transmission rate model that the limits of order perception have also been thought to depend on different rates of information transmission between the channels. Rutschmann conjectured that the central timing mechanism was accurate, with temporal order judgments being limited by the variability of sensory arrival times. Although these two models assume the independence of each input channel, interaction has been observed between different inputs as early as the transmission stage. For example, Pastore (1983) found that temporal order judgment thresholds for offset asynchronies were briefer than onset asynchronies due to the availability of some form of echoic information in the offset condition.

Reaction time experiments have suggested that the manual reaction times are different when two stimuli are transmitted along afferent pathways of differing lengths (Beaumont, 1974). This suggestion means that the central nervous system does not compensate for neural transmission time differences caused when pathways of differing lengths are stimulated. As a result judgments of the order of stimuli may not reflect their order in physical time.

Early psychophysiological studies indicated that 20 to 40 msec difference were required for human observers to judge correctly (75 per cent of time) which of two visual, auditory or tactile events occurred first (Efron, 1963a; Hirsch & Sherrick, 1961). The function relating discrimination of temporal order to the temporal separation between the two stimuli is monotonic when the discrimination is not dependent upon some complex interaction between the two stimuli whose order is to be perceived. The threshold for the perception of temporal order, under these circumstances, has been reported by Hirsh and Sherrick (1961) to be between 15 and 20 msec for trained subjects regardless of the mode of stimulation. For untrained subjects, Efron (1963a) reported threshold values of 60 msec. Comparing the results reported by Oatley, Robertson, and Scanlan (1969) to those reported by Efron (1973), it is indicated that long-duration intramodal stimuli, differing only with respect to onset asynchrony, require longer temporal separations than shorter stimuli or stimuli differing with respect to offset asynchrony.

Various values of the threshold were reported by Rutschmann (1973) depending on the site of stimulation and intensity of brief flashes, and by Warren (1974) with complex sequences of auditory stimuli (see Jones, 1985). Nevertheless, the largely hypothetical constancy of the temporal order threshold has suggested a role of central mechanisms rather than specific sensory ones. Although it was originally held that the threshold for temporal order judgement was lower for the auditory system than for the visual system , later work indicated that such a conclusion might have been based on methodological differences conventional to each modality (Hirsh & Sherrick, 1961). Thus, temporal order threshold between modalities does not differ markedly from those obtained within a modality.

For example, Hirsh Sherrick (1961) found that the particular value of the temporal order threshold was independent of differences in modality, intensity, or spatial localization. The interval required for 75 per cent correct discrimination of sequence was the same for visual, auditory, and tactile stimuli. Even some kind of simultaneity center common to all sensory modalities has been postulated (Efron, 1963a, 1963b). May, Williams, and Dunlap (1988) suggest that a consideration of the reading process tells us that from fixation to fixation the information must be encoded temporally although auditory information is arrayed temporally, while visually presented information is distributed in space.

From these results, Sternberg and Knoll (1973) supported the independent channel theory on perception of succession and of temporal order between two stimuli. According to this theory, a signal is detected after a random arrival latency. Since this latency essentially depends on the signal's specific characteristics, and perhaps on certain detection criteria, order judgments are determined by the difference between the arrival times of the information yielded by two stimuli presented through distinct channels. Based on the results obtained by Hirsh and Sherrick's (1961) experiment, Warren (1974) assumed that two processes are involved in discrimination and retention of temporal order within complex event sequences. In other words, serial order depends on rate limited verbal encoding and on training.

The threshold oriented approach conducted by Warren and Byrnes (1975) reflects the 20 msec order threshold value. They note that order judgments about arrangements of unrelated items such as hisses, tones that were embedded within the context of recycled sequences were not accurate unless event durations were at least 200 msec. According to this theory, event order is directly perceived only at durations in excess of 200 msec since this is the critical time to verbally encode each item. While subjects can learn to recognize very rapid sequences, this skill is assumed to depend on a different, holistic pattern recognition process which does not involve direct perception of individual event order. In short Warren's research testified the hypothesis that changes in rate alter one's experience of a sequence.

Furthermore, Jones (1985) points out that the more widely cited 20-30 msec temporal order threshold value (e.g., Ohgishi, 1981) must be qualified due to influences of event type, context and training among other things. In addition, two spatially separated visual targets, stimulated asynchronously, may give rise to a judgment based on motion, rather than a judgment of temporal order, thus yielding what appears to be psychophysical temporal order thresholds of less than 10 msec (Swisher & Hirsh, 1972).

Central Processing of the Temporal Order Judgement

One attempt to investigate the ordering of stimuli in time suggests that for the order of two or more stimuli to be distinguished representations of the stimuli must be transmitted to some common point in the brain where a mechanism for performing temporal order judgments resides. Judgments of order will reflect the arrival times of the neural representations of the stimuli at the mechanism and consequently would also be expected to be influenced by the lengths of the afferent pathways.

Lovegrove, Billings, and Slaghuis (1978) point out that, in normal subjects, temporal characteristics like temporal resolution or successiveness are idiosyncratic to the sensory modality, but temporal order is not. However, Efron (1963c) and Gibbon and Rutschmann (1969) have shown that stimulus differences (e.g. luminance) in the stimuli to be ordered result in differences in transmission times for the two messages which are not subtracted out by the mechanisms of the temporal order judgment and result in shifts of the point of temporal equality and asymmetries in the temporal order thresholds. This suggests that if early sensory mechanisms are rendered insensitive or more latent in response, temporal order judgments will be altered. An elaboration of this view might suggest that transient problems occurring during a critical stage of the development of the mechanism of temporal order judgments would lead to permanent or long lingering deficits.

These considerations have led to the suggestion (Efron, 1963a) that there may exist a central processing mechanism which is dedicated to the determination of temporal order irrespective of the modality of the stimuli to be judged. Guided by that notion, a number of investigators have studied the temporal order capabilities of various special populations of brain injured patients. It has been suggested that deficits of temporal order judgments imply an abnormality in the temporal lobes of the brain (Efron, 1963b). From their neuropsychological experiments Swisher and Hirsh (1972) concluded that the temporal lobe might have been appropriately named.

Correct temporal order judgment is the requisite factor not only for perception but also for long-term memory (see Grossberg, 1986). Estes (1972) notes that the inhibitory tendencies which are required to properly shape the response output become established in memory and account for the long-term preservation of order information. This leads to the assumption that inhibitory connections form from the representations of earlier items in the list to the representations of later list items such that earlier items will be less inhibited than later items on recall trials and will therefore be performed earlier.

From the view point of memory disorders, Milner (1971) emphasized a role of the frontal lobes in temporal ordering tasks. One good example of how the frontal lobes contribute to memory function comes from a study of memory for temporal order. In one experiment conducted by Milner, patients were shown a series of 184 stimuli, and were tested intermittently for their ability both to recognize the stimuli as familiar and to remember which of two stimuli had been presented more recently. Patients with unilateral temporal lobe lesions were deficient at recognition memory but had no additional difficulty with judgments of order. Patients with unilateral frontal lesions, but not temporal lobe lesions, were impaired in judging recency, though they performed normally at familiarity judgments. Performance on verbal and nonverbal tests has been averaged taking scores from left-damaged patients in the case of the verbal tests and from right-damaged patients in the case of the nonverbal tests. Patients with temporal lobe lesions were mildly impaired on the recognition memory test. In Petrides and Milner's (1982) study, patients inspected successive pages displaying up to 12 pictures of objects. The same set of stimuli appeared on each page, but they were always in a different arrangement such that subjects had to find on each succeeding page an item that had not yet been selected. This task required not only the ability to identify familiar items, but also the ability to relate information to one's own actions and to make selections among items that have been presented repeatedly. The results revealed that patients with frontal cortex lesions were severely impaired.

Results from temporal and frontal lesioned patients, both sites of the cortex seem to have relevance to temporal order judgement. Nevertheless it is possible to assume that the temporal lobes are less material-specific than the frontal-lobe in time-oriented situations.

Laterality Studies

Studies with both clinical patients and normal subjects have indicated that the left hemisphere is specialized in terms of temporal order, sequencing at both sensory and motor levels. In the latter case, the control of tapping, rapid sequential changes in limb, hand, articulator or finger positioning are included. Accordingly, the left hemisphere mediation of language does not seem to depend on its symbolic or phonological attributes, but rather depends on the need for analytic, time-dependent coding to occur both at receptive and expressive levels. This position views the left hemisphere as being adapted not for symbolic functions per se, but for the execution of some categories of motor activity that happened to lend themselves readily to communication.

With respect to temporal processing aspects, some researchers do not believe that these functions are unilaterally localized(Gates Bradshaw, 1977 Moscovitch, 1979;

Poeck & Huber, 1977; Swisher & Hirsh, 1972). Other researchers, however, seem inclined toward the unilateral position (Carmon & Nachshon, 1971; Efron, 1963a, 1963b, 1963c; Mills & Rollman, 1980). In addition, Molfese(1980) has developmentally investigated the temporal aspects of information available in the speech signal and suggested that there are unilateral left-hemisphere mechanisms sensitive to F2 transition cues and unilateral right-hemisphere mechanisms sensitive to voice onset time. Unilateral right-hemispheric specialization has also been claimed for some types of complex pitch discrimination (Sidtis, 1980; see Craig, 1979).

There is evidence for left-hemispheric specialization on a number of tasks involving the processing of temporal information. Various procedures and results of these laterality studies are summarized in Table 1.

To investigate temporal order judgments, there seems to be three approaches. One approach is to expect all judgments of order in time to be located in the speech hemisphere precisely because speech is a time based process requiring the detailed separation of sounds in time (Halperin, Nachshon, & Carmon, 1973; Papcun, Krashen, Terbeek, Remington, & Harshman, 1974). An alternative is to consider judgments of order in time to be a non-verbal activity and therefore locate this function in the non-speech hemisphere. A third approach is to limit the primacy of the left hemisphere in temporal resolution to the auditory domain, consistent with its predominance in speech perception (Natale, 1977), and to consider judgments of order in the visual modality to be consistent with the visual perception orientation of the right hemisphere.

Efron (1963a) assumed that the temporal order mechanism is located in the hemisphere which specializes in speech production which is usually the left hemisphere in almost right-handed subjects. In the visual experiment by Efron(1963a) subjects were asked to judge the simultaneity and temporal sequence of very brief (1 msec) bilateral stimuli, which were presented in either visual or tactual modalities (light flashes or electric shocks). In the right-handed subjects, the left-visual-field stimulus to be judged as simultaneous with a right-visual-field stimulus, the former must precede the latter by about 5 msec. He interpreted this as representing the time needed for callosal transfer of information from the right hemisphere to the left hemisphere. Left-handers were not significantly lateralized on this function, although they showed an opposite tendency in temporal ordering tasks. He suggested that the superiority of the left cerebral hemisphere in verbal performance results from its ability to recognize temporal sequences.

Furthermore, Efron (1963a, 1963b) concluded that the dominant cerebral hemisphere for language functions contains the simultaneity center. If this is true, then

Table 1. Summary of the Laterality Studies on the Temporal Order Judgment.

Author(s)	Modality	Subjects	Tasks	Results
Efron (1963a)	Vision & cutaneous sensation	40 normal subjects (20 right-handed and 20 left-handded).	Two squlses to subject's hands or two light flashes were successively presented. The two stimuli were initially separated by 100 msec and the interval was reduced by 5 msec steps until the subject responded with a judgment of simultaneity.	* There is a statistically significant differences between the right- and left-handed groups for both shocks and lights. * The right-handed subjects experienced their center points of simultaneity when the left stimulus preceded the right by 3.32 msec for shock and 3.81 msec for light. * The left-handed subjects experienced their criteria of simultaneity when the two stimuli were essentially simultaneous.
Efron (1963b)	Vision & cutaneous sensation	40 normal subjects (20 right-handed and 20 left-handed).	Two square pulses to subject's hands or two light flashes were successively presented under four stimulus intensity conditions.	* The right-handed subjects showed a greater deviation from true simultaneity when the stimulus intensity was weak than when it was strong.
Efron (1963c)	Vision & audition	12 left-hemisphere-damaged patients of whom 11 had some degree of aphasia and 5 control patient.	In the visual condition two flashes (5 msec duration) of different color were separated by various intervals of time from 0 to 600 msec, and the pair of flashes was repeated every four second. The subject was required to indicate whether the red or green light appeared first. In the auditory condition a pair of tones of 10 msec duration consisted of a high-pitched and a low-pitched pulses, and the subject had to report which sound was first when the pair of sounds was repeated every four seconds.	* The lesions which produce disturbances in the discrimination of temporal order are all in the hemishere which is dominant for speech functions. * Every subject with a dominant hemisphere lesion who had difficulty with temporal analysis also had some degree of aphasia. * The auditory temporal order analysis was more severely affected than the visual analysis.
Carmon & Nachshon (1971)	Vision & audition	47 patients suffering from unilateral lesions (21 left-hemisphere lesioned and 26 right-hemisphere lesioned) and 42 control patients free from neurological disorders.	The patients, presented with sequences of 3, 4 or 5 stimuli (3 colored lights and 2 sounds), chose any stimulus as a starting point, and identified the order of stimuli following it in the continuous sequence by pointing at the stimulus source.	* Performance of patients suffering from left hemispheric lesion was significantly impaired as compared with that of the other patients.
Swisher & Hirsh (1972)	Vision & audition	10 left-hemisphere-damaged patients, 5 right-hemisphere-damaged patients, 15 control subjects (5 pathological patients and 10 normal students).	Pairs of auditory (clicks) or visual stimuli (flashlamps) were presented and subjects were asked to indicate which member of the stimulus pair came first. The time difference between the onsets of the two stimuli varied from 20 to 640 msec.	* The control subjects required intervals between 30 and 40 msec to order two lights presented at the same place. * The left-hemisphere-damaged aphasics had large difference limens for all auditory tasks presented. * The right-hemisphere-damaged subjects required relatively normal intervals to order the visual stimuli, but required abnormally long intervals were necessary for two of the auditory tasks. * The right-hemishere-damaged subjects also had trouble discriminating between the paired sounds.
Halperin, Nachshon, & Carmon (1973)	Audition	36 right-handed female students between the ages 18 and 22 years (mean age 19.8 years).	Three sounds which varied in terms of either frequency (High or Low) or duration (Long or Short) were dichotically presented. Subject's task was to report the sequences by ear.	* As the number of frequency or duration transitions increased from zero to two, ear superiority shifted from left to right.
Sekuler, Tynan, & Levinson (1973)	Vision	4 subjects.	Brief visual stimuli were presented simultaneously or successively, one to the left and one to the right. The interstimulus delay was 2, 4, 8, 16, or 32 msec.	* A left-right pair is more easily discriminated from a simultaneous pair than is a right-left pair.
Babkoff (1975)	Audition	4 subjects.	The subject was instructed to indicate which stimulus (pulses) occurred first by depressing the key if the first stimulus appeared at the right ear, the left key if the first stimulus appeared at the left ear. The interval between the dichotic stimuli was varied from 2 to 128 msec.	* Temporal order discrimination is related to the dichotic temporal interval by a nonmonotonic, V-shaped function beginning with a high level of discrimination at short intervals decreasing as an interval increases to 8 msec, the increasing as an interval increases further from 12 to 128 msec. * The function of the left-first stimuli crosses the 75% discrimination level at approximately 6 msec while the function of the right-fist stimuli crosses the 75% discrimination level at approximately 18 msec.

Author(s)	Modality	Subjects	Tasks	Results
Bosshardt & Hormann (1975)	Audition	24 normal subjects.	Free recall performance for words dichotically presented to the right and to the left ear was analysed separately with respect to the correspondence between the sequence of presentation and that of recall.	* The sequence of presentation and the sequence of recall correspond to a greater extent in the case of right ear material.
Newman & Albino (1977)	Vision	9 right-handed undergraduates between the ages of 20 and 25 years.	Subjects were required to judge the temporal order of two physically simultaneous light flashes. Four stimulus conditions were administered with the left light flash being transmitted initially to the right hemisphere and the right light flash initially to the left hemisphere in all four conditions.	* Seven of the nine subjects had a larger number of 'left first' responses in the experiment. * The large amount of variability between subjects in the number of 'simultaneous' judgments was obtained.
Carmon (1978)	Vision	3 groups of left-hemisphere-lesioned, right-hemisphere lesioned, and control patients without any cerebral disease. Each composed of 20 right-handed patients. The mean age was about 50 years in all groups.	Subject were presented with spatial patterns composed of illuminated segments in the form of bars with a width of 10 mm and a maximum length of 60 mm. The segments were parts of an alphanumeric electroluminescent panel. Correct identification of the order of illumination was scored only if the subject identified the correct sequence in three consecutive delays.	* Lesions of the left hemisphere were found to increase generally the time needed for perception of sequences, whereas lesions of the right hemisphere were found to impair perception only in relation to the spatial complexity of the patterns.
Newman & Albino (1978)	Vision	5 students between the ages of 18 and 25 years, two of whom were female and the others male.	Subjects adjusted two light flashes until they appeared simultaneous. The psychophysical method used was the descending method of limits with the subject adjusting the interstimulus interval.	* The difference between the two stimulus condition is significant ($p<.01$).
Mills & Rollman (1980)	Audition	20 right-handed normal college student within an age range of 18-25 years.	Subjects were asked to report either the order or the simultaneity of two clicks when each was successively presented to a different ear.	* The threshold for temporal order was smaller when the right-ear click preceded the left-ear click compared to the opposite order of presentation.
Ohgishi (1981) Experiment 1	Vision	23 normal graduate and undergraduate student (16 right-handed, 7 left-handed). All were male subjects.	The descending method of limits with the experimenter adjusting the interstimulus interval was used to measure a threshold of simultaneity. Two light flashes (10 msec duration) were presented to each visual field and the subjects were required to press a telegraphkey when the two stimulus appeared simultaneous.	* The right-handed subjects reported their center points of simultaneity when the stimulus presented to the left visual field preceded the stimulus presented to the right visual field by 3.19 msec while the left-handed subjects reported their center points of simultaneity when the right stimulus preceded the left stimulus by 2.42 msec.
Ohgishi (1981) Experiment 2	Vision	33 normal graduate and undergraduate student (23 right-handed, 10 left-handed). All were male subjects.	The experiment consisted of the right-to-left and the left-to-right presentation conditions. Two flashes (10 msec duration) were separated by 30 msec interval of time from 0 to 600 msec and the subjects were required to indicate whether the right or left flash appared first.	* The right handed subjects responded more correctly in the right preceding condition than in the left preceding condition ($p<.05$) while the left-handed subjects showed no differences between two conditions.
Ohgishi (1981) Experiment 3	Vision	32 normal graduate and undergraduate student (23 right-handed, 9 left-handed). All were male subjects.	The experiment consisted of the right-to-left and the left-to-right presentation conditions. Two flashes (10 msec duration) were separated by 30 msec interval of time from 0 to 600 msec and the subjects were required to indicate whether the right or left flash appeared last.	* Sixteen of the right handed subjects responded more correctly in the right-to-left condition than in the left preceding condition ($p<.05$) while the left-handed subjects showed no differences between the two conditions.

Author(s)	Modality	Subjects	Tasks	Results
Sherwin & Efron (1981)	Audition	11 patients who had undergone unilateral temporal lobectomy for the treatment of medically intractable epilepsy.	Subjects were required to report the pitch sequence of two 10-msec tones of different frequency presented monaurally while the stimulus onset asynchrony between the two tones was varied. The value of the stimulus onset asynchrony at which the subjects achieved an 80% correct sequence report was determined by an adaptive procedure without feedback. This measure was compared in the right and left ears, on subjects with a right or left anterior temporal lobectomy and on a normal control group.	* The results reveal an elevated threshold for performing terporal order judgments in the ear contralateral to the surgical lesion.
Aram & Ekelman (1988)	Audition	12 left- and 12 right-hemisphere-lesioned children.	Subjects were required to discriminate, associate and sequence two nonverbal auditory stimuli.	* Unlike adults with left hemisphere injury or children with developmental language disorders, neither left- nor right-hemisphere-lesioned children differ significantly from control subjects matched by age, sex, race and social class.
May, Williams, & Dunlap (1988)	Vision (binocular)	14 3rd and 4th grade children who were selected on the basis of reading ability.	Two words (Box and Fox), were tachistoscopically (100 msec duration) presented to the left and right or above and below a fixation point. Subjects were asked to say which word came first under one condition, or which position contained the stimulus that occurred first under another condition. No feedback was given. The amount of time required to make accurate (75% correct) temporal order judgements was measured.	* Good readers required significantly longer stimulus onset asynchronies to achieve 75% correct than adults, but significantly shorter stimulus onset asynchronies than poor readers. * There was not a significant difference in thresholds for the word and position conditions for adults or good readers, but poor readers required significantly more time to achieve criterion for the word condition. * The word thresholds were highly correlated (−0.77) with reading level, but the correlation between position threshold and reading level was not significant.

information projected onto the right hemisphere must have at least one extra neural stage to go through, and hence may end up with a greater variability than information projected directly onto the left hemisphere. A series of experiments which assessed the threshold of simultaneity for visual and shock stimuli offered the finding which were interpreted as supporting the theory. There are similar indications in other experimental studies (Corwin & Boynton, 1968; Ohgishi, 1981; Oostenbrug, Horst, & Kuiper, 1978).

The notion of a left hemisphere specialization for judgment of temporal order has gained acceptance in the laterality literature (Beaumont, 1974). Davis and Wada(1977), on the basis of spectral analyses of visual and auditory evoked potentials to groups of flashes and clicks, concluded that the left hemisphere analyzes temporally ordered information and the right processes spatially distributed information. The temporal structure of both the click and flash would be more easily processed within the dominant hemisphere. These results are consistent with the hypothesis that the dominant and nondominant hemispheres are respectively involved in the analysis of temporally and spatially ordered information.

In the field of neuropsychological lesion studies, the majority of investigators have observed that patients with left-hemispheric lesions perform more poorly on discrimination of the duration of tones than do those with right-hemispheric lesions (Gordon, 1967; Needham & Black, 1970; Van Allen, Benton, & Gordon, 1966), although others have obtained just the opposite result (Chase, 1967; Milner, 1962). In any event, left-hemispheric specialization appear to extend to other discriminations requiring precise temporal judgments (see Gates & Bradshaw, 1977, for a review). Efron(1963b) found left hemisphere-damaged aphasic patients to have significantly higher temporal order thresholds for auditory and visual stimuli than right hemisphere-damaged patients, and both groups were significantly worse than normal controls.

Swisher and Hirsh(1972) replicated this basic finding, that is, when pairs of clicks or flashes were presented and subjects were asked indicate which member of the stimulus pair came first, the left brain-damaged subjects had larger difference limens for all tasks than the right brain-damaged subjects. The variations in this experiment depending upon sensory modality, spatial location of stimuli, features by which the stimuli differ, and type of aphasia present, however, indicate that many components contribute to the judgments required by temporal-ordering tasks. Consequently, Swisher and Hirsh (1972) concluded that the observed deficits in the ability to order stimuli temporally did not implicate exclusively a hypothetical or real time-ordering center although Efron's (1963c) conclusion that the left hemisphere is involved in the perceptual integration of events in time is especially appropriate for stimuli which arrive at one place.

Carmon and Nachshon (1971), requiring patients suffering from unilateral lesions to identify the order of audiovisual nonverbal stimuli in the continuous sequence by pointing at the stimulus source, found that performance of patients suffering from left hemispheric lesion was significantly impaired as compared with that of normal subjects and patients with right cerebral damage. It is possible that such deficit can be ascribed, not to an impaired verbal performance, but rather to a defect in processing sequences. Other studies with different stimuli provided similar support (Chedru, Bastard, & Efron, 1978; Sherwin & Efron, 1981).

Carmon (1978) and Natale (1977) review the extensive clinical evidence in support of this position and conclude that the left hemisphere is responsible for the sequential processing and temporal resolution of information, since lesions here typically result in that the patients needed more time to perceive order and sequencing, irrespective of spatial complexity. Right hemisphere lesions impair perception only in relation to spatial complexity of patterns rather than with respect to the perception of sequences. Conducting an experiment using an alphanumeric electroluminescent panel, Carmon (1978) conjectured the possibility that patients with left hemisphere lesions could benefit by using the spatial configuration as a clue to the correct order. This study also reported that damage to the left hemisphere resulted in an overall impairment of recognition of a visual sequence irrespective of its spatial complexity while damage to the right hemisphere did not affect perception of sequences unless the number of spatial components was increased.

It has been observed that the stimulus onset asynchrony have to be increased markedly before left brain-damaged subjects can reliably report the correct temporal sequence. These subjects are capable of making reliably correct temporal order judgments if the stimulus onset asynchrony was large. In the Sherwin and Efron (1981) study, subjects were required to report the pitch sequence of two 10 msec tones of different frequency presented monaurally while the stimulus onset asynchrony between the two tones was varied. The value of the stimulus onset asynchrony at which the subjects achieved an 80 per cent correct sequence report was determined by an adaptive procedure without feedback. This measure was compared in the right and left ears, on subjects with a right or left anterior temporal lobectomy and on a normal control group. The results revealed an elevated threshold for performing temporal order judgments in the ear contralateral to the surgical lesion. This means that the deficit cannot be attributed to any generalized cognitive disturbances, but is considered to represent a specific perceptive disability in the processing of rapidly presented sequential stimuli.

Furthermore, Sherwin and Hirsh (1981) summarized the results of the clinical temporal order experiments as follows. First, the severity of the deficit is greatest in subjects with left-hemisphere lesions that are associated with aphasia. Second, the severity of the deficit in patients with a left-hemisphere lesion without an aphasia may also be severe but the correlation is more variable. Although these studies implied a particular correlation with temporal lobe lesions, it is not possible to be certain what cerebral region has to be damaged before the deficit is produced. Similarly it cannot be determined whether there is any correlation between the size of the lesion and the severity of the temporal order deficit.

The viewpoint mentioned above is further supported by the observation that in left speech dominant patients, fine time discriminations between consecutive clicks are more affected by lesions of the left temporo-parietal (dominant) areas than lesions of the right. For example, Lackner and Teuber (1973) have shown that patients with penetrating wounds of the left posterior cerebral hemisphere have abnormal fusion thresholds, that is, these patients still report hearing only a single fused sound, even though the interaural temporal asymmetry is sufficient for normal subjects to report hearing two sound.

As to the handedness, the differences in temporal order judgments were found between right- and left-handed subjects (Efron, 1963a, 1963b; Ohgishi, 1981). On the basis of detailed analysis of the laterality of the left-handed subjects, Efron (1963b) concluded that the judgment of temporal asynchrony is executed by the hemisphere which is dominant for language functions. Carmon and Nachshon (1971) found that temporal order perception was more impaired by lesions in the left than in the right cerebral hemisphere in right-handed patients. In addition to this finding, Carmon (1978) points out that the validity of the dichotomy about temporal perception applies only to right-handed subjects. In left-handed subjects, damage to the right hemisphere compromised both the temporal and the spatial factors of perception while damage to the left hemisphere did not affect performance to a significant degree. Therefore, in left-handers no evidence was found for a complete reversal of the effect observed in right-handed patients.

Visual Studies

On the perceptual side, it has been shown for both the visual(Carmon, 1975; Carmon & Nachshon, 1971) and the auditory (Efron, 1963c; Halperin, Nachshon, & Carmon, 1973) sensory modality that the analysis of temporal and sequential order depends on the integrity of the left hemisphere (Gordon, 1974). In addition, tactile modality tasks yield essentially similar observations. Nachshon and Carmon(1975) studied hand preferences in the sequential localization of touched fingers and found that the right hand proved better on tasks requiring temporal analysis and the left on tasks where spatial relationships were most significant. Bakker and Van de Kleij (1978) obtained similar lateral differences in the localization of touched fingers under both dichaptic and unimanual stimulation.

Although these data illustrate the supramodal quality of the temporal performances of the left hemisphere, there exist some modality-specific characteristics to be noted. For example, Rutschmann (1966), using the right eye, obtained differences in the judged temporal appearance of stimuli at different locations of the retina. The results with paired flashes of light to the fovea and to the left or right periphery of the right eye produced greater asynchrony for four of the five subjects when the temporal hemiretina, rather than nasal hemiretina, was stimulated by the peripheral member. It seems that an eccentric stimulus had to appear before a foveal stimulus for the two to be judged as simultaneous, but this interval was smaller for the nasal than the temporal hemiretina. Therefore, a stimulus in one hemifield may appear to the observer to arrive in the central nervous system before a simultaneous stimulus in the opposite hemifield. These subjects seem to have possible dominance of the left side of the brain or the nasal hemiretina. Transmission of stimulation to the higher centers appears to be faster for stimuli presented to the nasal hemiretina. Evidence from reaction time experiments and temporal order judgment (Rutschmann, 1966) suggests that transmission of stimulation to the higher centers appears to be more rapid along the nasal visual pathways than the temporal pathways at similar visual angles.

Rutschmann also mentioned other data that indicated an effect of viewing eye. Assuming visual pathway differences, one would have expected the most left first judgments to be yielded when the right flash was presented to the left eye's temporal retina and the left one was presented to the left eye's nasal retina respectively. Although this expectation was not fulfilled in the experiment which required subjects to judge whether the flash were 'right first' or 'left first' (Newman & Albino, 1977), this was partially found in results of simultaneity experiments (Newman & Albino, 1978). These results suggest that some peripheral factors in the visual system must be considered as well as the central processing mechanism when conducting a visual temporal order experiments.

Regarding the difference between stimulus onset and offset asynchronies, Kapparuf and Yeatman (1970) tested right- and left-handed subjects in a perceived-order situation. The experiment was conducted by the up-and-down method to determine the relative on-latency for a visual test stimulus and a similarly defined relative off-latency for the same test stimulus. It was found that the algebraic difference between the relative on-latency measure and the relative off-latency measure. Previous data had suggested that this on-off difference was positive for left-handed subjects were found to differ significantly from the right-handed subjects in the magnitude of the on-off difference. This outcome was interpreted by the authors as a possible clue to functional interhemispheric differences related to handedness. Research on event-related potentials has provided data that are relevant to absolute duration threshold.

On- and off-responses evoked by onset and offset of brief visual stimuli have been recorded by Efron (1973), who found that off responses were found to be elicited by stimulus offset only when stimulus duration was longer than 50 msec. For duration between 5 and 50 msec off responses always appeared after an almost fixed delay following stimulus onset. The results shows that perception of flash was linked to the onset rather than to the offset of the stimulus.

As regards the methodological aspects of a visual temporal order experiment, four experimental conditions are possible according to whether the same or different stimuli are used and whether the stimuli occupy the same or different positions in space. With stimuli of different types, color or intensity will be confounded with temporal order. Using the same light stimulus in the same position involves a fusion experiment which is unsuitable for the investigation of laterality effects on normals, as eye movements cannot be prevented. According to Efron's hypothesis the right light flash should arrive before the left light flash in the temporal order mechanism as the left light flash would need to be transmitted from the right hemisphere to the temporal order mechanism in the left hemisphere. Consequently one would expect the subjects to have judged the right light flash directly sent to the left hemisphere as leading the flash pair more often than the opposite.

However, one condition of the Swisher and Hirsh (1972) experiment employed the same type of light flashes from different positions to normal subjects and failed to find any laterality difference. Newman and Albino (1977) could not support the predictions derived from Efron's work and suggested a right hemisphere specialization in visual temporal order. The authors suggested that the failure came from two methodological shortcomings which Efron's experiment holds.

First, Newman and Albino questioned Efron's criteria of excluding all subjects on the visual section of the temporal order threshold experiment. Efron(1963a) excluded those subjects who exceeded a standard deviation of 7 msec in more than one half of the visual experiments. This criterion led to a rejection of a large number of the subjects from the analysis, that is, in the major experiment on visual temporal order, only 9 out of 20 subjects succeeded in being included in the analysis, 11 having failed to fulfil the requirements of not exceeding a standard deviation of 7 msec in more than one half of the experiments. Since subjects in a simultaneity threshold experiment are free to select their own criteria (Sekuler, Tynan, & Levinson, 1973) and the notion that threshold measures are susceptible to a wide range of variables is supported by several perceptual studies (Corso, 1963), it is possible that this criterion would effect the results.

Second, in Efron's experiment employing the descending method of limits , the separation of the two stimuli initially presented was not sufficient enough to perceive a correct interstimulus temporal order. The two light flashes were separated by 100 msec at the outset of each descending series. It is important that subjects have a stable basis of separation on which to base their judgments of simultaneity.

In Newman and Albino's (1977) study 9 right-handed subjects were required to judge whether the lights were 'right first', 'left first' or 'simultaneous'. In all four conditions the right light flash was transmitted initially to the left hemisphere and the left light flash initially to the right hemisphere. The results of all four conditions yielded a greater number of 'left first' judgments, contrary to the predictions derived from Efron's hypothesis. Almost all the subjects had a larger number of 'left first' responses in the experiment. In order to predict more 'left first' judgments, the authors proposed one alternative explanation of the results that the temporal order mechanism resides in the right hemisphere of most right handers.

In addition to this experiment, Newman and Albino (1978) conducted a series of experiments in order to investigate the possibility of hemispheric specialization for judgments of the simultaneity of two light flashes. Five normal subjects adjusted two light flashes until the stimuli appeared simultaneous. Since the difference between the two stimulus condition was significant, the authors concluded that the result was contrary to Efron's hypothesis and was consistent with the proposal that the mechanism for temporal order resolution of brief light flashes resides in the hemisphere opposite to that of speech (right hemisphere in most right-handers).

Although Newman and Albino's criticism on Efron's experiment is per se quite reasonable, the number of subjects in their experiments is small as a neuropsychological experiment using normal subjects. Ohgishi (1981), testing larger number of normal subjects than Newman and Albino's experiments, supported Efron's results in both the experiment of simultaneity threshold and the experiment of temporal order judgments. In spite of the methodological problems, therefore, Efron's conclusion that the temporal order judgment is predominantly controlled by the left hemisphere seems to be accepted.

Some other explanations can also account for results of the visual temporal order judgments. It has been demonstrated that an internal perceptual scanning mechanism that scans from left to right (Sekuler, Tynan, & Levinson, 1973) and an attentional bias to the left visual field proposed by Kinsbourne (1970) have the prepotency of left-right perception of visual sequences. Sekuler, Tynan and Levinson (1973) administered an experiment where brief visual stimuli presented in rapid sequence, one to the left and one to the right appeared to occur left first, then right, regardless of the actual order of presentation. This illusion persisted under conditions of forced-choice testing and did not vary with presentation to the same or opposite retinal hemifields. In spite of these scanning and attentional effects, however, it has been reported that subjects make more 'right fast' response in prototypical visual laterality experiments (May, Williams, & Dunlap, 1988; Newman & Albino, 1978).

As the scanning habits are connected to reading ability, temporal order judgments have been also studied in a viewpoint of reading ability. Such a concept comes from work with dysphasic and dyslexic children, for whom there appears to have some deficits in perceiving the temporal order of nonverbal stimuli. Lovegrove, Billings, and Slaghuis (1978) assumed that some poor readers' deficiency in transient processing (rapid sequencing of visual events) would result in a temporal order judgment problem. Carrying out their experimental research within the framework of the Weisstein, Ozoc, and Szoc (1975) sustained/transient theory of visual perception, Lovegrove, Billings, and Slaghuis reported that temporal sensitivities are lower for all temporal frequencies in reading disabled subjects. Bakker and Schroots (1981) argued that the poor reader's problem centers around an inability to preserve temporal order. They have shown that when good and poor readers are asked to reproduce the sequence of different visual, auditory, or haptic stimuli, the latter group's performance was significantly worse than the former. However, the stimulus durations and the interstimulus intervals used in these studies were much longer than those used to measure the threshold for the temporal order judgment.

May, Williams, and Dunlap (1988) discussed the implications of reading disability in relation to a temporal order. The hypothesis that children with reading problems have difficulty judging the temporal order of visual stimuli was tested in a visual experiment. A range of stimulus onset asynchronies were selected such that it encompassed the threshold of human temporal order judgments and approximated the duration of eye movements during reading from the end of one fixation to the beginning of the next. The authors also attempted to determine if the temporal order judgment differences depended on reading or positional discriminations by measuring amount of time required to make accurate (75 per cent correct) temporal order judgements. Subjects were asked to say which word came first under one condition, or which position contained the stimulus that occurred first under another condition. Two words, BOX and FOX, were tachistoscopically presented in separate channels, to the left and right, or above and below a central fixation cross. Employing the psychophysical method of constant stimuli to determine each subject's threshold for temporal order judgement, the authors measured the threshold in terms of the stimulus-onset-asynchrony in msec required to detect which stimulus appeared first with an accuracy of 75 per cent. Based upon this performance the authors chose a stimulus onset asynchrony close to the estimated threshold. Two types of thresholds were obtained from each subject, that is, subjects were asked to indicate which word appeared first, or to indicate which position appeared first. The results indicate that good readers required significantly shorter interstimulus intervals to achieve 75 per cent correct than poor readers.

In all the studies of temporal perception discussed in relation to the reading disability, reading impaired children have been shown to perform more poorly than children with normal reading ability. However, Tallal (1980) claims that psychophysical studies with normal adults have shown that temporal analysis and sequencing tasks, of the type used in most studies with dyslexic children, are in fact dependent for normal performance on several more primary perceptual processes.

Auditory Studies

The auditory mechanism has been shown to be capable of resolving very small temporal separations between stimuli in dichotic situations. For example, when the interval between dichotic stimuli is increased to approximately 2-4 msec, two sounds are reported. Increases in interaural time asymmetry lead to the ability to judge temporal order (Hirsh & Sherrick, 1961). Babkoff (1975) notes that two trends of subjects' responses appear in a function relating discrimination of the dichotic temporal order of short-duration stimuli to the temporal interval separating them. At very short interstimulus intervals discrimination should be at a high level since an interaural loudness cue exists. As an interval increases, however, interaction between the dichotic stimuli decays, resulting in a decrease of loudness cue and of discrimination level. At longer intervals, temporal order judgment should increase as a function of interval.

Efron (1973) showed that the temporal separation is much shorter than the threshold for auditory temporal order judgment. When a pair of short-duration monaurally presented tone bursts of different frequencies (200 Hz) are presented with asynchronous offsets, subjects are able to discriminate them from a mirror-image pair with an offset asynchrony of 2.0 msec, since a different dominant pitch is associated with each of the two patterns. With longer duration stimuli, however, offset asynchronies of 20 msec and longer are necessary for discrimination. In Babkoff and Sutton's (1970) study monaural temporal intervals of 1.5 to 6.0 msec were sufficient for discrimination between mirror-image patterns of two unequal intensity transients in which one pair consisted of an intense stimulus followed by a less intense stimulus (1.5 msec to 6.0 msec) and the other pair consisted of the mirror image (same intervals), although these intervals were not sufficient to judge temporal order of the individual members of the pair of stimuli.

Regarding a laterality effect in temporal perception, Deutsch (1974) reported an example of auditory temporal illusion which was yielded in the experiment where subjects heard sequences of tones, alternating in frequency between 400 Hz and 800 Hz, each of which was dichotically presented for 250 msec and immediately succeeded the previous one. Although the perceived location of the tones seemed to alternate between ears, with the higher tone on the right and the lower tone seemingly located on the left, subjects reported only the sequence presented to the right ear. This results implies a left-hemisphere predominance of temporal perception as well as a dissociation between temporal perception and location perception. From the result that the right ear superiority was lager for right-handed subjects than for left-handed subjects, the author was compelled to consider that this effect was related to cerebral dominance. The auditory illusion, which is contingent on receiving a long sequence of tones, was interpreted as the left hemisphere predominance for rhythm (Craig, 1979), since other studies employing a similar procedure (Efron & Yund, 1976) could not obtain neither any ear superiority or any relation to handedness.

The prototypical picture of left hemisphere mediation of judgments of temporal order (Divenyi & Efron, 1979; Efron, 1963a, 1963b; Mills & Rollman, 1980) reflect capacities to process rapidly changing acoustic information and the ability to discriminate two sounds from one when they are very closely contiguous. With dichotic tests the left ear has shown an advantage in the processing of certain non-verbal sounds. Mills and Rollman (1980) employed two psychophysical methods to examine the role of the left cerebral hemisphere for the auditory discrimination of temporal order. Pairs of successive clicks were presented to the subjects such that on each trial one member of the stimulus pair was delivered to the left ear and the other member of the pair was delivered to the right ear. Normal subjects were asked to report either the order or the simultaneity of two clicks when each was presented to a different ear. The results showed that the threshold for temporal order was smaller when the right-ear click preceded the left-ear click compared to the opposite order of presentation. In relation to an hypothesis that the left hemisphere is the location for temporal processing in this task, these results suggest that the transfer of left-ear information needed for the temporal discrimination was done from the right hemisphere to the site of temporal analysis in the left hemisphere.

An alternative interpretation of the effect was also proposed by the same authors. From the hemispheric activation theory, when the left ear received the first click, the right hemisphere may have performed the task, but less efficiently than the left hemisphere. If this were the case, the ear superiority might be based upon the difference in accuracy or latency, rather than providing the basis for an estimate of interhemispheric transfer time. This notion would lead to a lower "noise level" of signals after being transmitted through the left hemisphere than through the right one, hence to a higher temporal acuity.

In addition to click sounds, tonal sequence stimuli including rhythm have temporal characteristics. These tasks suggest that the left hemisphere is specialized for judgments of temporal order, a finding which supports the more general notion of left hemisphere superiority for temporal processing. Using normal subjects, Halperin, Nachshon, and Carmon (1973) found that while the left ear was superior for simple tonal sequences (long and short), the right ear was superior for more complex sequences, when the number of temporal transitions became important. Robinson and Solomon(1974) obtained a similar right ear advantage using dichotic pairs of rhythmic pure tones.

Natale(1977) found a right ear superiority in the report of nonverbal rhythmic sequences, particularly for the more complex sequences and for the more dextral subjects. This author also concluded that this left hemisphere specialization for the temporal resolution of rhythmic sequences is part of a preliminary stage in the analysis-by-synthesis perception of speech, taking advantage of the fact that such patterns have a trajectory that can be tracked without constant monitoring. Gordon(1978) also found a right ear advantage in a dichotic test of melodies differing only in rhythm and concluded that the left hemisphere is concerned with the sequential, temporal aspects of the time dimension. In a similar vein, Papcun, Krashen, Terbeek, Remington, and Harshman (1974) using morse code found that skilled operators gave a right ear superiority for both complex and simple sequences while naive subjects gave a left ear superiority for complex sequences.

With verbal memory tasks, Bosshardt and Hormann (1975) presented words dichotically to the right and to the left ear and analysed free recall performance separately with respect to the correspondence between the sequence of presentation and that of recall. The results showed that the sequence of presentation and the sequence of recall correspond to a greater extent in the case of right ear material. These tasks all appear to involve the discrimination of fine temporal intervals and a greater facility for temporal resolution in the left hemisphere. What appears further necessary is to test whether auditory temporal discrimination is the critical mechanism determining laterality differences.

Conclusion

Although the left hemisphere seems to be prepotent in fine temporal analysis, there have been several reports in the literature which identify the right hemisphere as having a role in some kinds of temporal discriminations. Vroon, Timmers, and Tempelaars(1977) found that the left hemisphere is better at estimating simple reaction times, predicting time of arrival, and detecting short interruptions with auditory though not with visual stimuli.

Mills and Rollman (1979), however, showed left-hemisphere superiority for processing information relating to stimulus duration (unconfounded with the perception of temporal order, as in all the studies described below) when the durations were less than a critical value (50 msec or less), but above that value, the right hemisphere's participation appeared to be equivalent to that of the left. They noted that this duration is of the same order of magnitude as that required for achieving the perceptual distinctiveness of phonemes and speculated that both phenomena may depend on a specialized timing mechanism in the left hemisphere.

In a similar vein, Buchtel, Rizzolatti, Anzola, and Bertoloni (1978) found that subjects discriminated the duration of brief acoustic stimuli more quickly when the stimuli were presented to the left ear than when they were presented to the right ear. They concluded that the left ear is better able to discover the internal structure of a time series. Furthermore, Bertoloni, Anzola, Buchtel, and Rizzolatti (1978) found no evidence of hemispheric specialization in the discrimination of brief visual stimuli.

These data indicate that there might be some specialization of processing in time perception between the two hemispheres. According to the theory presented by Polzella, Da Polito, and Hinsman (1977) to account for cerebral asymmetry in time perception, neither hemisphere is more competent in making temporal judgments;

however, these judgments reflect different stimulus parameters. They considered that the left hemisphere may rely more on temporal information while the right hemisphere may rely more on nontemporal information.

A model of temporal perception proposed by Thomas and Weaver (1975) assumes that the perceived time of a brief visual stimulus is a function of two processors, a temporal (timer) and a visual-information processor. As visual information decreases, more attention is given to the temporal processor and perceived time is assumed to be a weighted average of the output of both processors. This model can be extended to the assumption that the hemispheric distinction serves as an automatic control over the distribution of attention to the temporal and the visual information processor (Polzella, Da Polito, & Hinsman, 1977). Temporal judgment will be based on the output of the visual-information processor when the stimulus is presented to the left visual field, while temporal processor will perform judgments when the stimulus is presented to the right visual field. In this context, Efron's finding (1963a, 1963b) of a simultaneity center in the left hemisphere may reflect the fact that the nontemporal parameters in the experiments were held constant.

In the experiment conducted by Koch, Polzella, and Da Polito (1980) where temporal and nontemporal information was varied, subjects were required to judge the duration of small and large colored circles. The authors found that over-all accuracy was equivalent in both visual fields, and the effects of size, color, and exposure duration did not interact when stimuli were presented foveally such that both hemispheres had simultaneous access to stimuli. Thomas and Weaver's model is supported by the findings that the changes in chromaticity of visual stimuli affected accuracy of temporal perception only in the visual field while changes in stimulus duration affected accuracy only in the left visual filed.

The variations in the findings on temporal order judgments indicate that many components contribute to the judgments required by temporal-ordering tasks. However, neither do the findings reviewed above preclude a central system for temporal ordering which is independent of the sensory mechanism. Furthermore, it is true that language, especially in its oral form, is fundamentally sequential, which suggests that the left-hemispheric specialization for language may have its origins in some more basic specialization for fine temporal programming. This theme should be further examined in cognitive and perceptual laterality studies.

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