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Visual Dominance: An Information-Processing Account of Its Origins and Significance

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In many situations, visual input tends to dominate other modalities in perceptual and memorial reports and in speeded responses. Visual dominance appears to be related to the relatively weak capacity of visual inputs to alert the organism to their occurrence. In response to this reduced alerting, subjects tend to keep their attention tuned to the visual modality. This bias works via prior entry to allow vision to control the mechanisms that subserve conscious reports. The study of visual dominance provides a model situation in which chronometric and phenomenological techniques can be brought together to produce a more complete picture of the relation between information processing and awareness.

Process models of perceptual phenomena (Chase, 1973) usually emphasize the flow of information within and between such systems as visual and acoustic analyzers, short- and long-term memories, and decision and response systems. Most often, some form of mental chronometry (Posner, in press), such as the measurement of reaction time, the use of backward masking, or the recording of electrical potentials, is used to trace the time course of information flow.

A different approach to perception has sought to determine the stimulus cues that shape our conscious awareness of an event (Koffka, 1935; Natsoulas, 1974; Stevens, 1957). Such techniques as verbal report, psychophysical scaling, or adjustment of stimuli to match along some specified dimension reveal little about the time course of mental operations but do tell which cues reach the processing levels capable of making conscious judgments. From this information it is possible to develop more detailed models of the stages of processing leading to awareness (Julesz, 1971), particularly when substantial electrophysiological studies are available.

Recently, efforts have been made to understand systems that subserve the functions of conscious awareness by locating them within an overall processing model. For example, Shallice (1972) viewed consciousness as a limited-capacity system related to the competition among inputs for access to effector mechanisms. LaBerge (1975) has provided a system in which the ability to excite nonhabitual pathways requires the intervention of such a limited-capacity attentional system.

The integration of information-processing and phenomenological approaches to perception has been hampered by the tendency to apply them to different problems. Processing models have dominated in the field of reading and speech perception, while classical perceptual methods have been more widely applied to the study of illusions, depth perception, and distortions of input arrays. In these latter situations, compelling phenomenal experiences occur that are not veridical in terms of the objective input.

The work reported here began with research undertaken independently by each author. Much of it is reported more fully in Klein (1974) and Nissen (1974). The theoretical position emerged in joint discussions among the co-authors. Preliminary reports of parts of these data were made at the Psychonomic Society, November 1973, at the meeting of the Western Psychological Association, April 1975, and at colloquium talks at several universities.

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It would greatly aid our understanding of information flow to have model experimental situations involving compelling subjective experiences that would also lend themselves to the techniques of mental chronometry. The phenomenological and chronometric approaches could then complement each other and provide better relationships to physiological systems that mediate information flow. In this article we shall attempt to apply a chronometric analysis to one of the most interesting, widely reported, and compelling phenomenological experiences—the tendency of the visual modality to dominate conscious judgments about the presence and location of objects.

Visual Dominance

A striking phenomenon that has been studied within the classical perceptual model is the tendency of visual information from an object to dominate perceptual and memorial judgments (Howard & Templeton, 1966). The classic case of visual capture was reported by Gibson (1933), who had subjects wear prism spectacles that made straight edges appear curved. When subjects watched their hands move along an objectively straight edge, visual information showed it to be curved. Although kinesthetic information indicated that the edge was straight, subjects experienced no conflict; the edge felt curved. The visual input dominated perception.

Rock and Victor (1964) reported visual dominance in judgments of size. Their subjects viewed a square object through a minifying lens but were not told of the visual distortion. In one condition they were asked to grasp the object and then to reproduce or match either its visual or felt size. The striking result was that both judgments depend on the perceived visual size of the object, not upon its actual size. Similarly, Pick, Warren, and Hay (1969) showed the dominance of visual input on the perceived location of an object. Subjects were asked to point with one hand hidden from view at a finger of the other hand, which they viewed through a lens that displaced the field by 11°. Subjects pointed very near to the optical position of their finger rather than to its felt position. Most subjects did not report the existence of any discrepancy between the two inputs.

The studies cited above all dealt with perceptual judgments in the presence of conflict between vision and kinesthesis.[1] However, visual dominance does not depend solely on the use of perceptual judgments, it does not arise only between vision and proprioception, and it does not depend on conflict.

Memory

Demonstrations of visual dominance are not limited to the perception literature; such effects are also found in memory tasks. One series of studies (Posner, 1967) compared the retention of visual and proprioceptive information. Visual information was greatly affected by an interpolated attention-demanding task, while proprioceptive information was unaffected. When both sorts of information were present, subjects behaved as they would have if only visual information were present.

Klein and Posner (1974, Experiment II) asked subjects to reproduce a movement pattern that was either visual, proprioceptive, or both. They found that subjects could quite easily ignore the proprioceptive information if instructed to reproduce on the basis of vision alone. The presence of proprioceptive information had an effect only when subjects were uninformed during presentation about which kind of information they would have to reproduce. On the other hand, proprioceptive reproductions were affected in the same manner by visual information whether or not the visual information had to be attended. Even when the subjects knew at the time of presentation that only kinesthetic information was to be used, they appeared unable to ignore the visual information present in the signal.

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[1] The terms *proprioceptive* and *kinesthetic* will be used interchangeably in this paper. The latter term is sometimes used to mean any information (including visual) that guides locomotion, but we are using both terms to refer to information arising from skin senses, joints, and muscle spindles during active or passive movement.

Vision Versus Audition

Evidence for visual capture is not limited to the comparison of visual and proprioceptive information. Pick, Warren, and Hay (1969) showed in a location task that vision also tends to dominate auditory location information. More recently, Colavita (1974) has published a series of experiments suggesting that when visual and auditory signals are presented simultaneously, subjects generally respond to the visual input and are often unaware that an auditory signal has occurred. Colavita first asked his subjects to match a visual and auditory stimulus for subjective intensity. These matched stimuli were then used in a choice reaction time task. Subjects were instructed to press one key whenever a light came on and another key whenever a tone occurred. Each of the 10 subjects received 30 trials. On 5 of these trials, both light and tone were presented simultaneously. Colavita found that in 49 out of 50 conflict trials, subjects responded only to the light. When subjects knew that dual presentations could occur, visual dominance was still present, although reduced. The Colavita study demonstrated the existence of visual dominance with chronometric methods rather than perceptual or memory judgments and by so doing, extended its implications.

Redundant Information

Another striking instance of dominance by vision was first reported by Jordan (1972) and confirmed in a slightly different design by Klein and Posner (1974, Experiment III). Reaction to a proprioceptive displacement cue is faster than reaction to a displacement cue presented only visually. When the two are made perfectly redundant, reaction time is greater than it would have been to a proprioceptive cue alone. Adding a redundant visual cue to a proprioceptive one causes an increase rather than a decrease in reaction time. This is a clear violation of the general tendency for redundancy to result in either no difference or an improvement in reaction time (Garner, 1974). This study, like the memory studies, extends visual dominance to situations in which there is no conflict between information given to two sensory modalities.

In summary, evidence for visual dominance has arisen in a number of quite different paradigms, some comparing visual cues with proprioceptive cues and others comparing visual cues with auditory cues. Dependent variables have included size reproduction, localization, reproduction of patterns, and reaction time. Each investigator has usually developed a theory of visual dominance that accounts reasonably well for the particular situation in which he has studied it. However, when all the information on visual dominance is combined, none of the accounts seem very satisfactory.

Theories of Visual Dominance

One explanation of visual dominance is tied to the spatial character of visual information (Rock, 1966). Rock proposed that vision directly yields spatial information but that touch provides such information only through its learned association with vision. This account does describe the results of studies using spatial localization or size judgments as dependent variables. It does much less well when one takes into account the reaction time data presented in the last section. The same objection applies to suggestions that the dominance of visual localization over auditory localization depends on the relatively greater accuracy of visual localization. Once again, this may describe the results using localization as a dependent variable, but it seems inadequate to handle visual dominance in general.

There have been some hints that visual dominance may relate to the development of locomotion. Lee and Aronson (1974) emphasized the importance of visual information as compared to mechanical proprioception in the development of an infant's ability to maintain balance. They found that visual information was dominant in the maintenance of balance both among infant subjects and adults. They pointed out that an infant's mechanical receptors are sensitive to changes in length and weight caused by the infant's rapid growth. The infant's mechanical proprioception is poorly calibrated in comparison to vision.

As a result, they argued that when an infant is learning to stand he must rely heavily on cues from vision. Once again, this explanation seems relevant to some aspects of visual dominance over proprioception but not over audition.

All of these ideas about the origin of visual dominance emphasize the reliability and accuracy of visual input. However, there are a number of recent results suggesting that visual dominance can break down under certain conditions. Moreover, there are also results that suggest that in some respects, the visual modality is a less efficient system for information processing than other modalities. We turn now to an examination of these facts.

Deficiencies of Visual Information Processing

One of the problems with methods involving verbal reports is that subjectively compelling and nonveridical observations are likely to be emphasized, particularly in secondary sources. The boundary conditions within which these observations occur are less well studied. There is evidence that visual dominance depends on the relations between the stimuli and on how the subject allocates attention. Warren and Cleaves (1971) used the spatial localization paradigm to explore different degrees of discrepancy between two modalities. They found that visual influence over kinesthesis was greater with smaller degrees of discrepancy (10°) than with larger ones (20°). These results suggest that it may be easier to attend to kinesthetic cues when they are more discriminable from the conflicting visual cues. In Garner's terms (1974), the ability to attend to one input code and ignore another may vary inversely with the integrality of the codes.

Many studies of the adaptation following exposure to conflict have shown that proprioception, not vision, is recalibrated (Harris, 1965). This is consistent with reports of visual dominance obtained in perceptual studies and suggests that proprioception is more labile than vision. Recent studies that have manipulated the locus of the subject's attention during exposure, however, have found no asymmetry; the modality that undergoes recalibration is the nonattended modality (Canon, 1970; Kelso, Cook, Olson, & Epstein, 1975). This result suggests that proprioception normally undergoes recalibration because of a tendency for subjects to attend to vision in the absence of instruction or incentive to the contrary.

The findings outlined above suggest that the integrality of stimuli used and the direction of the subject's attention affect the dominance of vision over other modalities.

In reaction time tasks there is a sense in which the processing of visual signals seems deficient in comparison with the processing of auditory and proprioceptive stimuli (Sanders & Wertheim, 1973). This concerns the degree to which the stimuli in a given modality serve to alert the organism about their presence. Posner (1975) described alertness as a state in which the organism's central decision-mechanism system is activated and made ready to respond to incoming information. The alerting effect of a warning signal presumably depends on its ability to place the decision mechanism at a heightened state of readiness to respond. Our work (reported later in this article) suggests that visual stimuli are less alerting than stimuli in other modalities. In this article we shall demonstrate how the relatively inferior alerting capability of visual signals may help to account for the tendency of vision to dominate other modalities.

A New View of Visual Dominance

A theory is briefly outlined in this section, and evidence that has been developed so far is summarized in the following sections. For the most part, this theory arose out of the evidence rather than the reverse. But it will be more useful for the reader to know where we are going before attempting to follow us through the maze of experimentation that has been generated in the course of trying to understand the basis of visual dominance. Moreover, the propositions used to develop this theory of visual dominance are more general than the study of visual dominance itself. For that reason, they may be important as a basis for a more general theory of the comparison of modalities, in addition to their application to the question of visual dominance.

Proposition 1. Visual stimuli are not as automatically alerting as stimuli in other modalities.

Proposition 2. In order for a visual event to serve as an effective alerting stimulus, the subject must first process it by active attention.

Proposition 3. The consequence of active attention toward any one modality is a reduction in the availability of the attentive mechanisms to input from other modalities.

Proposition 4. To compensate for the low alerting capability of visual signals, subjects exhibit a general attentional bias toward the visual modality whenever they are likely to receive reliable input from that modality. This bias may not be obvious to them, but it can be viewed as a strategy of a very pervasive sort.

The view implied by these propositions suggests that under some circumstances, visual information will dominate other sources of sensory input, while under other circumstances it will not. The elements of this view are all rather nonobvious, and some are probably counterintuitive, especially from the point of view of visual dominance. They must all be qualified within the framework of experimentation that supports them. In each of the following sections we consider one of the propositions and discuss evidence that favors it. Virtually all the data have been collected within the chronometric framework.

Proposition 1—Visual Signals Are Less Alerting

This proposition has been investigated within a moderate range of experimental conditions, and these conditions provide boundaries for the effects we report. In general, the visual signals we used were always of small size, rapid onset, and moderate intensity. They appeared in the fovea under conditions of light or moderate dark-adaptation when the visual field was nearly empty.

Intersensory Facilitation

In a choice reaction time task, subjects respond to the imperative stimulus faster when it is accompanied by an irrelevant accessory stimulus in a different modality. For a long time, this effect was attributed to an increase in the discriminability of the imperative stimulus. However, a more recent viewpoint (Nickerson, 1973; Nissen, 1974) suggests that the effect of an accessory is essentially the same as that of a warning signal. Rather than increasing the discriminability of the imperative stimulus, the accessory causes the subject to respond sooner to the information building up in his memory system. The earlier the response, the less accurate it is.

We used the intersensory facilitation paradigm to investigate the alerting characteristics of visual and auditory stimuli. In one experiment (Nissen, 1974), the subject's task was to decide whether an X appeared to the right or the left of the fixation frame. On four-fifths of the trials, the visual imperative stimulus was accompanied by an auditory accessory (a burst of white noise). In another experiment, the imperative stimulus was either visual or auditory. An X could appear on the right or the left of the fixation frame, or a tone could be presented to the right or left ear. The subject pressed the right key when either the X or the tone was on the right, and the left key when either of the stimuli was on the left. On four-fifths of the trials, there was a visual accessory stimulus, consisting of a square flash of light in the center of the fixation frame. The accessory could precede or follow the imperative stimulus by up to 100 msec.

The results are presented in Figure 1. They allow us to compare the effects of a visual accessory on a visual task, a visual accessory on an auditory task, and an auditory accessory on a visual task. It appears that an auditory accessory is more effective than a visual accessory in reducing reaction time to the imperative stimulus. When an auditory accessory and a visual imperative stimulus occurred simultaneously, reaction time was reduced by about 40 msec. However, when a visual accessory occurred at the same time as either a visual or auditory imperative stimulus, little or no facilitation occurred. Neither the 5-msec reduction of mean reaction time on the visual task nor the

12-msec reduction on the auditory task was significant.

The auditory accessory stimulus produced a very clear effect on visual processing throughout the range of intervals studied. The effect produced was a reduction in reaction time together with an increase in errors. This trade-off is exactly what occurs with increases in alertness introduced by warning signals (Posner, 1975). The visual accessory affected processing only when it preceded the imperative signal. The usual explanation of this asymmetry attributes it to the fact that auditory signals are processed more rapidly than visual signals. Thus an auditory accessory will affect a visual task even when it occurs together with or following the visual signal, but the reverse will not occur. To test this notion, we turn to warning signals that are introduced at intervals considerably in advance of the imperative signals.

Warning Signals

Warning signals serve to alert the organism to the presentation of the imperative signal. The great bulk of the literature on warning signals has dealt with an auditory warning signal followed by either an auditory or a visual task, or with a visual warning signal

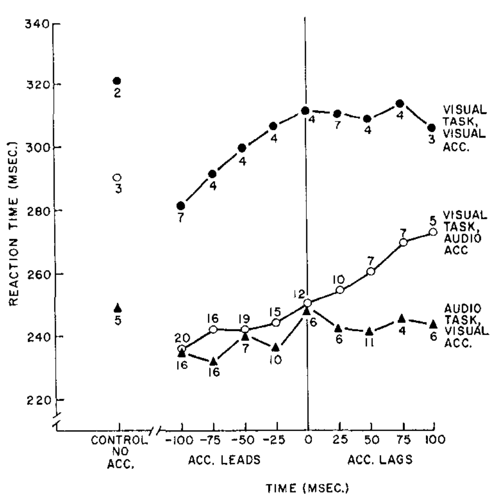

FIGURE 1. Performance on visual and auditory choice reaction time tasks when an accessory stimulus presented in close temporal proximity to the task was in the same or in a different modality. (Numerals indicate the percentage of errors.)

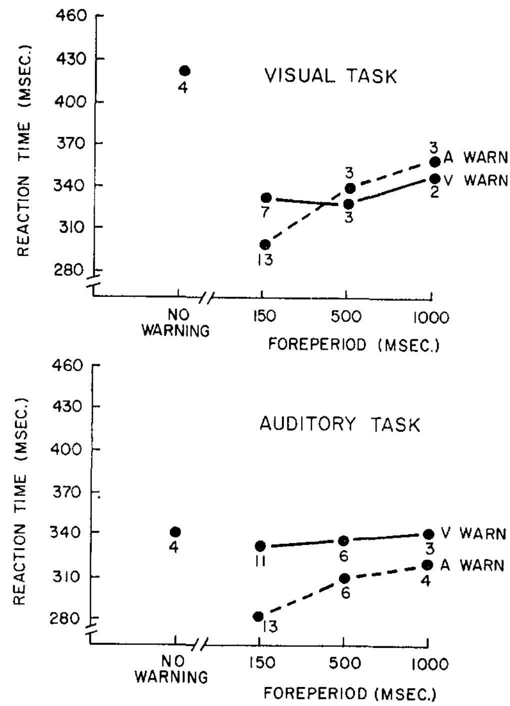

FIGURE 2. Performance on visual (top) and auditory (bottom) choice reaction time tasks following auditory-, visual-, and no-warning signals. Subjects were equally likely to receive a visual or auditory task. (Numerals indicate error percentages.)

followed by a visual task. Rarely have investigators used a visual warning signal followed by an auditory task (particularly under conditions of modality uncertainty).[2]

We conducted experiments that showed visual and auditory warning signals to have different effects on visual and auditory tasks. In one experiment, within a block of trials, subjects could receive either a visual or auditory warning signal followed (with equal likelihood) by either a visual or auditory task. The visual warning was a 50-msec square flash of light in the center of a fixation frame, and the visual task required the subject to press the key under his right index finger if an X appeared in the right half of the frame, and to press the key under his left index finger if an X appeared in the left half of the frame.

[2] However, auditory signals have been reported to be less affected by temporal uncertainty than are visual signals (Sanders & Wertheim, 1973).

The auditory warning signal consisted of a 50-msec burst of white noise, and the auditory task involved pressing the right key in response to a 500-Hz tone in the right ear and pressing the left key in response to the same tone in the left ear. Blocks of trials were given with no warning and after foreperiods of 150, 500, and 1,000 msec following a warning signal.

The results for eight subjects are shown in Figure 2. Performance on the visual task (upper half) was about the same whether the warning signal was visual or auditory. Although there was some tendency for an auditory warning to be superior at very short foreperiods, the bulk of the results suggest that the two warning signals were equally successful in facilitating the visual task. The results for the auditory task (lower half), however, show a different pattern; auditory responses were significantly faster when the imperative signal was preceded by an auditory warning. A visual warning provided no facilitation for the auditory task in this situation. Error data, also included in Figure 2, indicate the usual increases in errors following a warning signal. This increase is similar regardless of warning signal modality. All of these results have been replicated using nonlocalization tasks.[3]

The nature of the peculiar reaction time interaction immediately eliminates many of the most likely explanations of the effect. One might suppose that the auditory warning signal was simply more intense than the visual warning. In that case, the two auditory warning conditions would have been more effective than the two visual ones. Another view might be that the auditory imperative signal was itself so alerting that it would not benefit from a warning signal.[4] Clearly, though, an auditory task *can* benefit from a warning signal provided that the warning is auditory. Another explanation might be that the auditory warning signal was processed more rapidly than the visual warning signal. Clearly, this explanation could account for results occurring when the intervals between warning and imperative signals were brief, such as in the intersensory facilitation studies. However, it surely cannot account for the effects that occurred nearly 1,000 msec following the warning signal.

Probe Reaction Time

There is another sense in which vision seems to be inferior to audition and kinesthesis in its alerting capabilities. The detection of visual stimuli is influenced by the allocation of attention more than is the detection of auditory or proprioceptive stimuli. In one demonstration of this effect (Nissen, 1974), subjects were first presented with a bimodal (visual and auditory) warning signal. It was followed by a stimulus indicating whether the imperative stimulus, which occurred 1,000 msec later, would be visual or auditory. Subjects were instructed to press one key in response to a small X or a soft tone and a different key in response to a large X or a loud tone. During the 1,000-msec interval before the imperative stimulus, subjects presumably developed a set for either vision or audition. On one-tenth of the trials, either a visual or auditory probe occurred during that interval. The visual probe was a square flash of light, and the auditory probe was a burst of white noise. Subjects were instructed to respond to these probes (with a third key) but to consider the choice task as more important.

The results show that reaction time to the auditory probes was unaffected by whether the subject was expecting an auditory or visual task. On the other hand, reaction time to visual probes was about 45 msec slower when the subject was expecting an auditory task than when he was expecting a visual task.

Klein (1974) investigated the effects of the

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[3] Recent data (Jones & Kabanoff, 1975) suggest that the presence of eye-movements might be involved in the relative ability to perform auditory localization tasks. It is possible that the visual warning inhibits such movements and thus affects auditory localization. However, we repeated this experiment using high and low tones as the auditory imperative stimuli and high and low digits as the visual imperative stimuli. Although there was no localization involved in the task, the results obtained were the same as in the erperiment described here.

[4] This view has been adopted by Sanders (1975) to explain foreperiod effects with visual and auditory tasks. While it is undoubtedly partly correct, it does not seem adequate to handle our results.

locus of attention on visual and tactile detection. His subjects received simultaneous visual and kinesthetic input, but within a given block of trials they were instructed to attend to only one modality. In a visual block, their task was to indicate whether a dot had moved to the left or the right and to ignore the direction in which their finger was passively moved. In a kinesthetic block, subjects were to respond to the direction of the finger movement and to ignore the visual movement. The direction of the movement in the irrelevant modality could be the same or opposite that of the attended modality. Visual probes consisting of a square flash of light at the center position, and tactile probes consisting of the vibration of the subject's finger, were presented randomly within each trial block. Klein found that responses to the tactile probe were equal in latency in the visual and kinesthetic blocks but that responses to visual probes were nearly 30 msec slower in the kinesthetic blocks than in the visual blocks. Once again, it appears that vision is more influenced by the locus of the subject's attention.

Switching Time

Perhaps this asymmetric effect of the locus of attention on responses to visual and nonvisual input has something to do with the ease of switching attention from one modality to another. One meaning of visual dominance suggests that it is more difficult to switch *from* vision than it is to switch *from* another modality. If the visual information tends to capture and hold the subject's attention, then the time required to switch from vision should be longer than that required to switch from other modalities. On the other hand, an account of visual dominance based on the relatively poor alerting qualities of visual stimuli would predict the opposite result: It should not be more difficult to switch from vision than to switch from another modality, but rather, more difficult to switch *to* vision than *to* another modality. Klein (1974) used a method first developed by LaBerge (1973) to compare the time to switch *from* vision and kinesthesis (to audition), as well as the time to switch *to* vision and kinesthesis (from audition). The subjects' attentional sets were manipulated by instruction and by the proportion of trials within a block that used the attended modality. For example, prior to a visual block, subjects were instructed to attend to vision, and the block consisted of 40 visual trials and only 4 auditory and 4 kinesthetic trials.

The visual stimulus was the motion of a fixation dot toward the left or right of the cathode ray tube. The kinesthetic stimulus was a similar passively imposed motion of the right index finger toward the left or right. The auditory stimulus was presented to the left or right ear. Subjects responded with their left hand by pressing a key in the direction of the movement.

To compare the time to switch *from* vision with the time to switch *from* kinesthesis, Klein examined auditory response latencies when subjects switched from an expected visual and an expected kinesthetic stimulus. He found no differences, which suggests that visual input did not capture attention in the sense of delaying switches to other modalities. When the time required to switch to a modality was examined (by measuring the increase in reaction time when the modality was unexpected), there was a much larger increase in reaction time to an unexpected visual stimulus than to an unexpected kinesthetic one.

All of these results can be summarized by the proposition that visual stimuli when unattended are less likely to alert the subject than stimuli occurring in other modalities.

Proposition 2—Alerting Based on Visual Stimulation Requires Effort

If visual stimuli are deficient in alerting capability, how is it possible for us to have shown that a visual warning signal improves the processing of a following visual task? One answer lies in distinguishing between *automatic* alerting effects (which are powerful in auditory and proprioceptive input) and *effortful* alerting effects (which can be obtained equally from any input). An automatic alerting effect occurs when the central decision-making mechanism is activated without attention being directed to the warning signal. Effortful alerting effects require the subject to turn his attention to the processing of the warning signal. According to this distinction, a visual warning signal should be successful in facilitating response to an auditory event if the subject is certain that an auditory event will follow the visual signal. When certain of this, the subject can use the visual signal to turn his attention deliberately to the auditory modality. Such a situation is quite different from one in which the subject does not know whether the following event will be visual or auditory.

To investigate this question, we used visual and auditory warning signals in an experiment nearly identical to the one reported earlier. Subjects received a visual or auditory warning followed by an auditory task. The task was to determine whether a pure tone was presented to the left ear or the right ear. Since vision never provided any information relevant to responding, the subjects should have resisted any tendency to attend visual input.

The results are shown in Figure 3. In this situation, visual warning signals provided as much facilitation of reaction time for an auditory task as auditory warning signals did. An analysis of variance showed no significant effect of warning signal modality. There was, however, a significant interaction of warning signal modality and foreperiod. When a visual warning signal occurred only 150 msec before the imperative stimulus, seven out of eight subjects reacted more slowly than they had when they received an auditory warning at

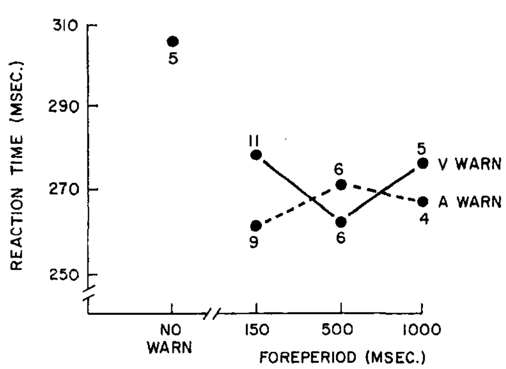

FIGURE 3. Performance on an auditory choice reaction task following visual-, auditory-, and no-warning signals when there was no uncertainty about the input modality of the task. (Numerals indicate the error percentages.)

that interval. This might mean that a subject who receives a visual warning signal must switch attention to audition. Presumably, this switching and the subsequent development of an auditory set following a visual warning are not complete by 150 msec, but when the subject is allowed at least 500 msec to prepare for the auditory task, preparation is as good following a visual warning signal as following an auditory warning signal. The advantage of auditory warning signals at brief foreperiods is also shown in Figure 2 and could as well be due to the automatic alerting effects of audition. The benefits of that alerting would be expected to influence responses at short foreperiods.

The interaction between modality of warning signal and rate of preparation for the imperative task also appears in the contingent negative variation (CNV) following warning signals in different modalities. Gaillard and Näätänen (Note 1) measured the depth of the CNV 500 and 1,000 msec after visual and auditory warning signals. They found that the depth of the CNV 500 msec after an auditory warning signal was significantly greater than that after a visual warning signal. By 1,000 msec after the warning signal, the depth of the CNV was similar for visual and auditory warning signals. These results further confirm the relatively automatic nature of the auditory warning as compared to the visual warning.

In this section it has been shown that both visual and auditory warning signals can serve as sources of alerting effects when subjects know the modality of the imperative signal. However, when the warning signal is visual, it is necessary to adopt a deliberate set toward the warning signal. The consequences of a modality set are discussed in the next section.

Proposition 3—Costs and Benefits of Sensory Set

In previous work, Posner & Snyder (1975a, 1975b) developed a cost-benefit analysis of attentive processes. The idea behind such an analysis is the separation of active attention involving limited-capacity mechanisms from the activation of pathways not involving these mechanisms. The same type of analysis may be used to study the deliberate commit-

TABLE 1

SENSORY SET: A COST–BENEFIT ANALYSIS

Response	Probability of specified modality			Cost	Benefit
	.8	.5	.2		
Visual task					
Mean reaction time (msec)	258	269	295	26	11
Percentage of error	5	4	6	2	−1
Auditory task					
Mean reaction time (msec)	212	229	265	36	17
Percentage of error	4	6	7	1	2

ment of the processing capacity mechanism to an input modality. The idea is simple. Pure alerting activates the central processing mechanism and makes it available to any input item. It thus improves the speed of processing of all items that might be presented to the organism. On the other hand, a deliberate effort to couple active attention to a particular modality will inhibit central processing of signals in other modalities. Obviously, the extent to which the unattended signal forces itself upon the subject by its automatic alerting character might reduce or mitigate the effects of such a deliberate stimulus set.

To test this idea, we presented subjects with blocks of trials in which an auditory task might occur 80% of the time, 50% of the time, or 20% of the time. On the balance of the trials, a visual task was presented. The auditory task involved pressing one of two keys to indicate whether a tone had occurred in the left or right ear. The visual task was to press one of two keys depending on whether an X occurred to the left or the right of a center line. The benefit obtained when a signal occurred in the expected modality was measured by subtracting the reaction time when that modality occurred 80% of the time from the reaction time when it occurred only 50% of the time. The cost of receiving a signal in an unexpected modality was measured by subtracting the reaction time in the 50% block from the reaction time when the expected modality occurred only 20% of the time.

The results are shown in Table 1. Both the auditory and visual modalities show significant costs in reaction time when they are unexpected, and smaller, though significant, benefits when they are expected. More striking costs were obtained when probability was manipulated within blocks through the use of a warning signal that indicated the most likely modality of the following imperative signal.

One unexpected result of the cost–benefit analysis in both of these experiments was that the low-probability visual event did not produce relatively greater cost than the low-probability auditory event. According to the notion that visual events are less alerting, one would have expected it to take longer to switch to the visual modality than to the auditory modality. This kind of result occurred with the probe and switching tasks discussed earlier. There are, however, several possible reasons for the failure to find an asymmetry between the two modalities. If subjects are usually directing their attention toward vision, a given probability manipulation may not be as effective for that modality. The discrepancy might also result from the nature of the auditory and visual tasks used in this experiment. To measure switching time, it seems better to use a probe detection task than the more complicated discrimination task used in this study. The visual task required subjects to indicate whether an X was located to the left or the right of a center line. All the needed information was presented on the screen. However, the auditory task required subjects to determine whether the presentation of a stimulus was to the left or right ear. This discrimination may be more difficult when attention is shifted from an orientation toward vision to audition.

In any case, there seems to be reasonable support for the third proposition of our view of visual dominance. Once having turned attention to a particular modality, information on another modality is less readily processed than if the subject is in a neutral set. A bias toward one modality affects the ability of signals in the other modality to reach the central processor. In the experiments presented here, subjects were able to respond to the unexpected modality, even though their responses were somewhat delayed. In the Colavita (1974) studies, subjects sometimes showed not just an increase in reaction time to the auditory stimulus but also an absence of awareness of it. Colavita has also shown that the more reason the subject has to expect simultaneous signals to the two modalities, the more likely he is to process the auditory stimulus. We believe that increases in reaction time to an unexpected stimulus can lead to its complete exclusion from conscious processing under some conditions. The doctrine of prior entry (Titchener, 1908) holds that those stimuli arriving at the attentional mechanisms first tend to exclude those that arrive later. We are a long way from knowing in detail what distinguishes conditions that produce complete exclusion from conditions that produce a switch from one modality to the other. Given the Colavita result noted above, it appears that the subject's knowledge of the likelihood of bisensory signals increases the probability that switching will occur. An important point to note here is that what shows up as small changes in reaction time in one paradigm might show up as exclusion from awareness when subjects have no real incentive to switch their attention to respond to the other stimulus.

The results presented in this section provide the necessary tools to account for our warning-signal effect. When subjects receive an auditory warning signal, their central processing mechanisms are alerted, but their attention is not closely coupled to any modality. Thus, the warning signal has roughly equal effects whether the following task is visual or auditory. When a subject is presented with a visual signal, there is little or no automatic alerting, and subjects attend strongly to the visual modality. If the following signal is visual, they will show improved reaction time. However, if the following signal is not visual, they will show a lesser improvement or even an overall cost in processing efficiency. If the visual warning signal is consistently followed by an auditory signal, the subject can process the visual signal and then switch his attention to audition, thus obtaining the usual benefits of a warning signal.

Proposition 4—A Bias Toward Vision

Jordan (1972) showed that when subjects are asked to respond quickly to simultaneous and redundant visual and kinesthetic inputs, they tend to base their response on the visual input even though they could respond faster by attending to the kinesthetic input. Jordan trained novice fencers to initiate a fencing move when the foil they were holding was deflected by a mechanical foil. One group of subjects was blindfolded and thus had to rely on the kinesthetic and tactile information provided by the movement of their foil. Another group could watch the movement and were thus allowed both visual and kinesthetic input. A third group also watched the movement, but their foils were placed 15 cm from the mechanical one so that the initial information was only visual. Reaction time in the condition providing visual and kinesthetic input was 27 msec slower than that in the pure kinesthetic condition.

Klein and Posner (1974) and Klein (1974) replicated this effect using slightly different stimuli and responses. The proprioceptive input consisted of the passive movement of the subject's finger to the left or right, and the visual input was the movement of a dot to the left or right of a scope. On bimodal trials, the two movements were always compatible. Subjects had to indicate the direction of movement by pressing one of two keys. In one experiment, trials were blocked by modalities, and each subject performed a visual block, a kinesthetic block, and a bimodal block. In agreement with Jordan's (1972) results, responses to proprioceptive inputs

TABLE 2

PURE AND MIXED BLOCKS IN A REPLICATION OF THE JORDAN (1972) EXPERIMENT

Response	Pure blocks			Mixed blocks		
	Visual	Kinesthetic	Bimodal	Visual	Kinesthetic	Bimodal
Mean reaction time (msec)	317	248	261	337	260	243
Percentage of error	2.9	4.0	4.6	1.8	10.7	7.9

were significantly faster than responses to bimodal inputs (see table 2). However, they were not nearly as slow as for vision alone.

To find out what would happen when subjects could not rely on vision, Klein (1974) used a mixed-block condition. Within a block, subjects could be presented with either a visual stimulus, a proprioceptive stimulus, or a bimodal stimulus. Since it was sometimes necessary to use proprioceptive information, bias toward vision would not work on all trials, and a more even distribution of attention ought to result.

The results are shown in Table 2.[5] Reaction time to bimodal trials in mixed blocks was significantly faster than reaction time to kinesthetic trials alone (redundancy gain). A simulation of the bimodal reaction times based upon the unimodal times suggested that in the mixed-block condition, subjects responded to whatever information was detected first.

It seems that when information about an event is available from vision *and* from audition or propioception, and when the visual information is adequate for responding, attention is directed to vision. In conditions in which vision does not provide adequate information, visual bias no longer prevails. This interpretation implies that in conflict situations, when vision and proprioception or audition provide discrepant information, vision will usually dominate unless the subject is instructed or infers that responses based on vision will be incorrect. In many cases the dominance is incomplete, just as it is in many of the studies reported in this article. In the conflict studies mentioned earlier (Rock & Victor, 1964; Pick, Warren, & Hay, 1969), subjects were naive with respect to the conflict. They did not expect to receive discrepant information and thus could assume that responses to the visual input would be appropriate. Telling subjects to attend to the nonvisual input as Pick, Warren, and Hay (1969) and Klein and Posner (1974) did, is evidently not sufficient to reverse the visual bias unless subjects also know that vision will be inadequate to provide a correct response. The success of an instructional manipulation probably also depends upon the degree of integrality of the stimuli (Garner, 1974). When the information presented to eye and hand comes from quite separate loci, such as in most of our work, it is probably much easier to direct attention than it is when the information comes from a single position in space, such as in much of the prism conflict work.

Recent studies in the prism literature (Canon, 1970; Kelso, Cook, Olson, & Epstein, 1975) are consistent with the notion that attentional factors can affect the degree of visual dominance. Our studies provide little information allowing for detailed prediction of the nature of judgment in any given situation. Obviously, many aspects of training, integrality, instruction, individual differences, and relative accuracy of the kind of information presented will determine the direction and degree of dominance in any given experimental situation.

[5] There are a number of features of interest in the data of Table 2 that do not relate closely to the main points raised here. One of these features is the large error rates found in the kinesthetic mixed block trials. We believe this is largely due to a strong automatic alerting effect of the kinesthetic information that results in faster but more error-prone RTs. If so, it seems likely that the alerting property of the kinesthetic information has some effect even in the pure bimodal blocks (note high error rate in this condition). This is one aspect of a more micro account of how the two kinds of information are used that goes beyond the scope of this paper (Klein, 1974).

CONCLUSIONS

What has been learned from our studies of visual dominance? In general, our results support the four propositions outlined earlier and seem to point to an account of visual dominance as a bias in the direction of the attentional mechanism toward the visual modality. As we conceive it, this bias is a general phenomenon that serves to couple the attentional mechanism more closely to vision than to other modalities of input. A useful analogy one might consider is that of a computer system in which the central processor is more or less directly coupled to a high-priority user (vision) whenever otherwise unoccupied; other users (proprioception, audition) would need to summon attentive processing since it would not normally be as readily available to them.

Somewhat surprisingly, once attention is placed on a modality, the difficulty of switching off that modality appears to be roughly equal whether the modality is vision, audition, or proprioception. Switching time is heavily a function of the depth of processing in a given modality (LaBerge, 1973), but this appears equally true of all modalities. When not being attended, vision is at a disadvantage in terms of switching time because its priority interrupt is simply less efficient.

It is not our intention to assert that this simple mechanism is by itself responsible for visual dominance wherever it is found. Undoubtedly, many of the special explanations outlined in the introduction, which account for visual dominance in different specific situations, also play important roles. However, we feel that the remarkable relation among input modality, central alerting, and attentional strategies will need to be considered when sensory dominance is studied in the future.

Origins of Visual Dominance

Why does a bias toward vision occur? It is this question that some of the theories of visual dominance outlined in the introduction have sought to address. We have no certain answer. It is possible that vision's deficient alerting capability makes it necessary for subjects to learn to direct their attention to vision. It is also possible that causation goes in the other direction. An attentional bias toward vision would make it unnecessary for vision to develop the strong connections to alerting mechanisms that other modalities have. Our finding that dominance is very labile gives some reason for supposing that the causal direction is from the alerting deficit to the attentional bias rather than the reverse.

One possible cue might be the ready availability of the eye-movement system as a response to visual input. If visual signals tend to evoke eye movement automatically, it may be unnecessary for them to also summon attentional systems unless the input is further classified as dangerous or interesting. This idea would fit with results (Posner & Snyder, 1975b) showing that much semantic processing of visual information can occur outside of attention.

The developmental data suggests that visual dominance is as likely to be present in children as in adults. Unfortunately, our results do not provide either an evolutionary or developmental framework within which to explain visual dominance. However, they do tell us something about where one ought to look to develop such a theory.

It should be noted that the theory we present is a rather complex combination of physiological (hardware) and psychological (software) propositions. Among the former is our suggestion that the visual system is more poorly coupled to alerting mechanisms than are other modalities. On the other hand, some of the elements of our theory are psychological in the sense of strategic responses to task environments. Subjects seem capable of adapting to their own nervous system constraints by broad-scale strategies. The study of such adaptations in different tasks may eventually help us understand the origins of visual dominance.

Significance of Visual Dominance

Regardless of the origins of visual dominance, the ability to obtain it in a wide number of experimental situations indicates both its importance in human functioning and its likely contribution as an experimental tool. The phenomenological study of visual dominance via the use of perceptual reports (Rock & Victor, 1964; Pick, Warren, & Hay, 1969), indicates that the visual modality may block information occurring in other modalities from awareness. These reports testify to the power of the effect and to its compelling phenomenal nature. Phenomenological study, however, has rarely placed emphasis on the boundary conditions within which such reports can be obtained. Nor does the study of visual dominance through the use of perceptual reports provide any detailed account of the level at which the nonattended information arising from other modalities is excluded. The chronometric study of visual dominance not only confirms its existence but has shown in more detail the nature of the conditions under which it occurs. Moreover, it provides techniques for more analytic studies dealing with the microstructure of conflict between modalities that might occur in a given task with an individual subject (Klein, 1974; Warren & Platt, 1975).

Psychology is concerned both with the mental content of consciousness and also with how information flow produces access to consciousness. The phenomenological report technique provides evidence that vision dominates at the level of conscious mechanisms. The chronometric analysis provides methods for dealing with the question of how visual information obtains control of these mechanisms. The treatment of this model phenomenon by both techniques may be a vehicle for a more complete account of the relationship between the activation of pathways in the nervous system and the summoning of the systems underlying conscious attention.

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Announcement

The Publications and Communications Board of the American Psychological Association announces the appointment of William K. Estes as editor of *Psychological Review* for the years 1977 to 1982. Beginning April 15, 1976, manuscripts should be directed to:

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