CHAPTER EIGHT

Psychophysiological Correlates of Imagery[1]

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Recent behavioral studies have shown clearly that nonverbal imagery is a major factor affecting memory, language, and thought (Paivio, 1971). The studies also have gone a long way toward revealing the functional characteristics that distinguish imagery from verbal symbolic processes. Some neuropsychological research, such as the work on the functional asymmetries of the cerebral hemispheres (Kimura, 1966; Milner & Teuber, 1968; Sperry, 1968, 1971), has contributed to this differentiation by demonstrating that the mechanisms subserving verbal and nonverbal processes are, to a considerable degree, distinct anatomically as well as functionally. Psychophysiological studies have provided further support for the validity of the imagery construct but such studies have generally lagged behind behavioral research in their contribution to theoretical understanding in this area. This paper reviews some of the attempts to

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[1] Preparation of this paper and the author's research reported in it were supported by grants from the National Research Council of Canada (APA-0087) and the University of Western Ontario Research Fund.

find theoretically useful psychophysiological correlates of imagery, with particular emphasis on our own work on pupillary reactions. To provide a framework for the discussion, I will first describe our theoretical and empirical approaches to the concept of imagery, and briefly outline some of the distinctions between imaginal and verbal processes as revealed to date by behavioral research.

I. THEORETICAL DEFINITION OF IMAGERY

Like any inferential construct, imagery can be understood only by comparing and contrasting it with other processes that have distinct theoretical and empirical properties. In our research, we have distinguished between imaginal and verbal processes. The underlying mechanisms are viewed as independent but interconnected systems for the storage, manipulation, and retrieval of stimulus information. The imagery system is presumably specialized for dealing with information concerning relatively concrete objects and events. The verbal system is also useful for dealing with concrete information, and in addition it surpasses imagery for the representation and manipulation of abstract information. A further distinctive feature of *visual* imagery is in the way units of information are organized. Visual imagery, like visual perception, is apparently specialized for parallel processing—the information in visual images is organized spatially thereby permitting simultaneous access to its components. Verbal processing, on the other hand, is sequential—units of information are organized sequentially into higher-order units, although parallel processing also occurs in the operational sense that verbal units can be processed to some extent independently of each other. A third distinction is that imagery is a dynamic process, capable of rapid transformations, whereas the verbal system may be relatively less proficient in transformational thinking. This is exactly the reverse of the traditional view that images are static portraits and of such contemporary views as Bruner's (Bruner, Olver, & Greenfield, 1966), according to which imagery is relatively sluggish and untransformable whereas the verbal system is swift and flexible in its functioning. Nevertheless, it is the direction in which theory seems to be moving at present (see Berlyne, 1965; Paivio, 1971).

1. *Empirical Distinctions*

Obviously these theoretical distinctions can be useful only to the extent that imaginal and verbal processes can be operationally distinguished as well. During the introspective era of psychology, researchers distinguished between the two processes on the basis of introspective evidence related to vividness of quasi-perceptual experience related to different sensory modalities. Thus concrete nonverbal visual imagery was distinguished from auditory or kinesthetic speech imagery, and so on. The emphasis on subjective vividness as a defining attribute of the imagery construct is still dominant among some researchers (Richardson, 1969; Sheehan, 1966). Unfortunately, however, reported vividness of imagery has been relatively unsuccessful as a predictive variable, both in the early history of imagery research as well as more recently, so we have relied mainly on other approaches while recognizing that introspective reports can sometimes be a useful adjunct.

We have used three major classes of independent variables: stimulus attributes, experimental manipulations, and individual differences in symbolic habits and skills. In the stimulus approach, imagery is defined in terms of the image-evoking value of the stimulus as measured by subjects' ratings or reaction time data. For example, a large sample of nouns has been scaled on the ease with which they arouse images (Paivio, Yuille, & Madigan, 1968). This approach extends to pictures and objects at the high imagery end, and to larger verbal units such as phrases and sentences at the linguistic level (Begg & Paivio, 1969). The experimental approaches have included manipulations designed to increase or decrease the probability that imagery or verbal processes will be effectively used in a particular task. This has been done by instructing subjects to use imagery in the task (Paivio & Foth, 1970; Yuille & Paivio, 1968), or by varying the rate of presentation of items (Paivio & Csapo, 1969), and so on. The third approach involves measurement of individual differences using spatial manipulation tests as well as questionnaires to define imagery ability (Ernest & Paivio, 1969). The differential availability of such processes also can be inferred from sensory deficits such as blindness or deafness (Bugelski, 1970; Paivio & Okovita, 1971).

2. *Functional Characteristics of Imaginal and Verbal Processes*

Some of the theoretical distinctions between imagery and verbal processes, as inferred from empirical evidence, will now be summarized. It is in regard to these points in particular that the psychophysiological findings will be evaluated later on.

Functional independence of the underlying systems. First, the two symbolic systems are assumed to be functionally independent. Evidence from memory research involving manipulation of relevant item attributes and experimental manipulations provides compelling support for this generalization (Paivio, 1971). For example, the verbal code can be made functionally unavailable using pictorial stimuli presented at such a fast rate that they cannot be implicitly labeled, yet they can be recalled or recognized, apparently on the basis of stored visual images alone (Paivio & Csapo, 1969). Pictures are recalled better than words, however, at slower rates when both codes presumably are available, suggesting that they are additive in their effects on recall—two independent codes for the same target memory are better than one. Functional independence is also supported by neuropsychological findings concerning functional asymmetries of the cerebral hemispheres in perception and memory for verbal and nonverbal material (Kimura, 1966; Milner & Teuber, 1968; Sperry, 1971). For example, lesions in the left hemisphere can result in selective impairment of memory for verbal material without impairing memory for nonverbal material, and vice versa for lesions in the right hemisphere.

Interconnectedness of the two systems. A second important generalization is that, although independent, the two systems become functionally interconnected through associative experience involving language and concrete events. This means that words can be transformed into images, nonverbal stimuli can be labeled, and transformations can occur cognitively from images to implicit speech and vice versa. Introspective evidence is particularly compelling on this point. Suppose I ask you to describe your living room. The input is verbal and your description verbal, but the mediating memory is likely to involve a nonverbal visual representation of the layout of your living room. I believe that it is in fact always such a memory, except among blind people who must make use of other modalities in the task. The example illustrates interconnectedness because it involves transformations from verbal input, to memory image, to verbal output. The introspective evidence is amply supported by research involving, for example, mnemonic techniques that apparently require such transformations, and by memory studies involving verbal recall of pictures, or pictures as mediators of verbal recall (see Paivio, 1971; Reese, 1970).

Task concreteness and availability of the symbolic processes. Still another generalization is that the arousal and functional usefulness of imagery varies directly with the concreteness of the stimulus situation and task. The verbal system is not similarly dependent on concreteness. This simply means that concrete objects and events or their linguistic descriptions readily evoke nonverbal images, whereas abstract concepts, relations, and tasks do so less readily if at all. Verbal processes, however, are readily evoked by abstract as well as by concrete stimuli. This implies that the relative advantage of verbal processes should increase as the stimulus situation and task increase in abstractness. This generalization is overwhelmingly supported by reaction time studies which have shown that images are aroused much more quickly by concrete than by abstract words or phrases, whereas the speed of verbal associative reactions is not similarly affected by abstractness. The results of learning and memory studies involving such stimuli are also consistent with this view (Paivio, 1971). Findings from some of the pupillary research that I will review later bear directly on this point.

Parallel versus sequential processing. A fourth point is that the two systems differ most clearly in their relative capacity for parallel and sequential information processing. In particular, the information contained in visual images is apparently organized spatially, so that the components can be processed synchronously. Imagery is relatively inefficient, however, for sequential processing of discrete item information. Conversely, the verbal system is specialized for sequential organization, presumably because of its auditory motor nature, but spatial organization is probably difficult in verbal terms alone. The superiority of the verbal system for sequential processing was demonstrated in a study (Paivio & Csapo, 1969) which showed that recall of pictures was inferior to recall of words in a sequential memory task, such as immediate memory span, when the rate of presentation was too fast to permit implicit labeling of the pictures, but not at a slower rate where such labeling could occur during input. However, pictures did not suffer when the tasks did not require memory for item order.

The postulated superiority of imagery for spatial organization is intuitively compelling and is supported by some experimental findings as well. For example, the finding from tachistoscopic recognition studies (Bryden, 1960) that verbal stimuli are reported more accurately from left to right than from right to left, whereas arrays of nonverbal stimuli are reported equally accurately in either direction from the immediate memory image is consistent with the generalization. So, too, is the finding that paired associate learning of pairs of concrete nouns, such as *elephant–ambulance,* is facilitated by presenting pictures of the objects in some kind of interactive relationship (Epstein, Rock, & Zuckerman, 1960; Wollen, 1969), or by instructing subjects to form mental images of such relationships (Bower, 1970), but not if the depicted objects are separated. Some relevant neuropsychological evidence on functional distinctions between the cerebral hemispheres is also available (see Kimura, in press; Sperry, 1971), but I am aware of no psychophysiological studies that bear on the issue.

Independence of symbolic systems and sensory modalities. The final theoretical point that deserves mention here is that the distinction between verbal and nonverbal symbolic processes is conceptually distinct from differences in sensory modality. This means simply that both verbal and nonverbal stimulus information can be visual, or auditory, or haptic, or some combination of these. The idea that symbolic and sensory modalities are orthogonal has important implications for memory research (see Paivio, 1971, Chap. 7), and it is an area where psychophysiological studies should be particularly valuable although no relevant information appears to be available at present.

Other theoretical distinctions can be made, but the ones I have summarized are best supported by available evidence from behavioral research. We will now consider in more detail what, if anything, has been revealed about such distinctions by psychophysiological studies, and what contributions such research might make in the future to the understanding of the processes underlying the various phenomena that behavioral studies have revealed or supported. The review begins with a brief discussion of EEG recordings and eye movements as possible correlates of imagery, and then deals at greater length with our attempts to relate pupillary reactions to imagery activity.

II. ELECTROENCEPHALOGRAPHIC STUDIES

In 1943, Golla, Hutton, and Walter initiated a line of investigation that has continued at least sporadically up to the present time. The research has focused on the relationship between EEG patterns and modes of thought, in the hope that individuals could be classified into different cognitive types on the basis of a purely objective, physiological measure. For example, Golla *et al.* (1943) reasoned that people classified as habitual visualizers should show an absence of alpha rhythm, whereas habitual verbalizers should show unusually persistent alpha. The underlying assumptions were that visual imagery, like visual perception, involves activity in the occipital cortex and that the occipital alpha rhythm therefore will be absent or attenuated among those whose habitual mode of thinking is visual-imaginal, whereas verbal thinking is mainly auditory–kinesthetic in nature and should be associated with persistent occipital alpha. Results purporting to support such distinctions were obtained by Golla, Hutton, and Walter as well as by a number of subsequent investigators (Short, 1953; Short & Walter, 1954; Slatter, 1960). However, other studies reviewed by Oswald in 1957 and more recently by Richardson (1969) failed completely to find differences in EEG patterns as a function of imagery type. One problem with the early research was that many investigators used unspecified or ad hoc methods of assessing imagery types. In addition, the scoring of a subject's EEG and the assessment of imagery type usually were not done independently, thus introducing potential experimenter bias. In 1956, Barratt manipulated the mode of thinking experimentally rather than in terms of individual differences alone. He presented his subjects with mental problems that required either visual imagery or verbal thought for their solution. He concluded from his results that suppression of the alpha rhythm was not associated reliably with visual imagery as defined by the experimental task.

Simpson, Paivio, and Rogers (1967) further investigated the relation between EEG activity and imagery using Barratt's experimental tasks and correcting for some of the shortcomings of the earlier research involving individual differences. Specifically, rather than using an ad hoc method of assessing imagery types, we used an objective spatial manipulation test (The Minnesota Paper Form Board), along with rating scale measures to assess the subject's visual imagery ability. Second, the EEG records were scored independently by an experimenter who had no involvement in the experimental task. We obtained significant results that contradicted those reported in previous investigations of the relation between EEG and imagery. Whereas Golla *et al.* (1943) reported that visual imagers had little or no resting alpha, we found that high imagers had greater EEG amplitude than low imagers during a control condition involving resting alpha. Moreover, we found lower alpha amplitude during the verbal task than during the visual task, which goes contrary to the hypothesis that greater occipital activity, hence greater desynchronization of occipital EEG activity, is involved in the visual than in the verbal problem. The results, however, can be interpreted in terms of general activation or arousal related to task difficulty. When an independent sample of subjects completed both the verbal and the visual problems, we found that the visual task was correctly answered by many more subjects than the verbal task, suggesting that the latter was the more difficult. Thus the greater alpha attenuation during the verbal as compared to the visual task could be due simply to greater cognitive arousal associated with the former. Be that as it may, our findings and the results of other studies on the problem are generally inconclusive in that there seems to be no firm evidence that imagery can be differentiated from verbal thought in terms of alpha blocking.

Perhaps Kamiya's recent work (cited in Stoyva & Kamiya, 1968, pp. 201–203) on the operant control of the EEG alpha rhythm will be a more fruitful approach to the general problem. The most relevant point in the present context is that when alpha was "on" Kamiya's subjects reported that they felt relaxed and were not experiencing any visual imagery. During periods of alpha suppression, on the other hand, the subjects reported "seeing" things. However, alpha was also suppressed if they reported exerting mental effort of some kind, suggesting that the physiological correlates may not be specific to imagery. They may be related instead to verbal processes, general cognitive arousal, or simply to asymmetrical lateral movements of the eyes, which Bakan and Svorad (1969) found to be negatively correlated with EEG alpha activity when a subject is engaged in a reflective mental task. Obviously the problem is complex and it will probably be some time before the various contributing factors are teased apart.

Whereas the conclusions from the study of general EEG wave patterns are somewhat discouraging, research involving average evoked potentials appears to be a more promising approach to the study of physiological correlates of the symbolic processes. Particularly interesting is John's (1967) discussion of the relation between meaning and the shape of evoked potentials recorded from the brain. John, Herrington, and Sutton (1967) had demonstrated that different geometrical patterns, such as a square and a circle, elicit evoked potentials differing in shape. John refers to further unpublished work (pp. 410–411) which showed that wave shapes resembling those normally evoked by a particular geometric form can be obtained in response to illumination of an empty visual field if the subject merely imagines that the same form is present in the field. Different reactions were also obtained to the printed words *square* and *circle,* which were equated for area. John raises the interesting question of whether subsequent research can demonstrate an invariant aspect to the wave shape of responses evoked in the same region by presentation of a geometric form and the name of the form. Such demonstrations would be extraordinarily interesting in relation to the kinds of problems I have been discussing, especially in that they might reveal something about the specific content of imagery aroused by stimulus words, but I will curb my enthusiasm until the hard data are in.

III. EYE MOVEMENTS AND IMAGERY

I turn to a brief discussion of the relationship between eye movements and imagery. The issue is especially interesting because it implies that imagery involves a motor component that gives it a dynamic quality quite different from the static quality attributed to images by the ancient wax tablet model and the more recent photograph analogy. Thus, such diverse theorists as Hebb, Skinner, and Piaget have assumed that motor processes are important in imagery, although they do not insist that such processes need be manifested in peripheral motor reactions. Hebb (1968) suggested that eye movements, or imagined movements, facilitate the formation of a clear image. Skinner (1953) discussed imagery in terms of both "conditioned seeing" and "operant seeing." In the case of the latter, the private events include implicit motor activity comparable to that involved in the perception and manipulation of objects. Piaget (Piaget & Inhelder, 1966) defines imagery as internalized imitation, paralleling the motoricity involved in perceptual exploration, in which movements "imitate" the contours of a perceived figure.

Relevant evidence has been provided by studies that investigated the relationship between eye movement patterns and imagery as inferred from subjects' reports. Perhaps the most dramatic demonstration of a positive relationship is the study by Roffwarg, Dement, Muzio, and Fisher (1962), in which an interrogator, working only with the dream narrative, was able to predict with remarkable accuracy the number, direction, and timing of rapid eye movements that occurred during the dream sequence. Increased eye movements have also been reported during periods of imagery activity among awake subjects by Lorens and Darrow (1962), and Antrobus, Antrobus, and Singer (1964). A study by Deckert (1964) is particularly interesting because it appeared to provide rather unequivocal evidence of the perceptual nature of imagery. His subjects first observed a beating pendulum and then were asked to imagine the movement. Deckert reported that the subjects developed smooth pursuit movement of a frequency comparable to that of the previously visualized pendulum, rather than saccadic movements, which would be normally expected with eye movements in the absence of a moving object.

However, the observed correlations between eye movements and imagery can be interpreted in several ways. One possibility is that the eye movements reflect the scanning of an experienced image. Thus Roffwarg and his colleagues suggested that the rapid eye movements constitute the physical representation of the dreamer's "watching" of the visual imagery of the dream. Lorens and Darrow proposed similarly that increased eye movements in their study reflected scanning of visual images during mental multiplication. Deckert suggested that the necessary prerequisite for the pursuit eye movements in his experiment was the development of an appropriate cerebral image. His finding appears to support an "outflow" theory of eye movement control, in which that control presumably is initiated by the central activity (imagery). More recently, however, Graham (1970) reported that he failed to obtain a similar correspondence between eye movements during actual observation of a moving pendulum and movements recorded during the imagination of such activity. Deckert's particular interpretation in terms of an outflow theory must therefore be regarded as questionable at this time. The internal scanning interpretation of rapid eye movements during dreaming also fails to be supported by recent evidence (Rechtschaffen, 1971).

Another possibility is that the eye movements, rather than reflecting implicit scanning activity, are involved in the generation, or regeneration, of imagery by proprioceptive feedback cues. Suggestive evidence of such a process can be found in Ivo Kohler's (1964) research. The relevant finding was that negative afterimages resulting from the prolonged wearing of colored filters occurred subsequently in response to eye movements, apparently as a result of sensory conditioning in which motor feedback from eye movements functioned as the CS for the negative afterimage. The evidence at least makes it plausible that a similar mechanism might operate in relation to visual mental images as well. Hefferline and Perera's (1963) finding that the auditory image of a tone could be conditioned to a thumb twitch can be similarly interpreted to mean that one function of the motor component of an image is to provide feedback stimulation that would trigger a further sensory response, and so on, in an imagery chain.

The interpretations I have suggested and other possible ones encounter the problem that eye movements are sometimes absent during imagery. As early as 1910, Perky reported that eye movements did not occur during images of imagination, although they accompanied memory images. More recently, Singer (1966) reported that eye movements did not occur during daydreamlike thought. Perhaps the best experimental evidence on the issue has been presented recently by Hale and Simpson (1971). They required their subjects to generate images to noun pairs under instructions to make eye movements, to think about making eye movements, or to do neither. The latency and rated vividness of mediating images were the dependent variables, and eye movements were continuously monitored by means of electrooculograms. They found no significant effect of the eye movement conditions on either latency or vividness of images. Moreover, the rate of occurrence of eye movements was unrelated to image latency and vividness. Thus we are faced with negative evidence concerning both the internal scanning and the proprioceptive cuing hypotheses of the relationship between eye movements and imagery. What, then, is the precise role of eye movement tendencies and other motor processes in the control or modulation of imagery? Obviously we need more data before that question can be answered. Thus far, then, neither EEG recordings nor eye movement have been found to correlate consistently with imagery if we accept subjective reports and reaction times under imagery instructions as valid indicators of imagery. In the remainder of the paper, I shall consider where studies of pupillary reactions have taken us in the search for such correlates.

IV. PUPILLARY REACTIONS DURING IMAGERY TASKS

My interest in pupilography began naively with the hope that pupillary reactions might reflect specific characteristics of memory images. Jaensch (cited in Klüver, 1932) reported that children classified as having eidetic imagery showed pupillary constriction when asked to imagine bright objects, and dilation when asked to imagine dark objects. This observation, if reliable, has remarkable implications concerning cognitive influences on an autonomic response. I shall return to these. First, let us consider the more modest possibility that pupillary dilation might at least correlate in a reliable way with the act of imaging, if not with specific attributes of images.

1. Effects of Imaging to Concrete and Abstract Words on Pupillary Dilation

It has long been known that the pupil dilates when a person engages in almost any kind of mental activity (Hess & Polt, 1964; Lowenstein & Loewenfeld, 1962). That is, the pupil gets bigger when we think about something or attempt to solve a problem mentally. Moreover, it dilates more when the cognitive task is more difficult than when it is simple (Beatty & Kahneman, 1966; Hess & Polt, 1964). The research I did in collaboration with Drs. Herb Simpson and Frank Colman, and subsequently pursued by them, was concerned with the effect of an imagery task on the magnitude and latency of dilation. Earlier research had established that it is more difficult to generate images to concrete than to abstract words, as measured by ratings of ease of imagery (Paivio, 1965) and imagery reaction times (Paivio, 1966). We reasoned that these differences would also be reflected in pupillary dilation.

We investigated the problem in a series of experiments involving the following procedure. The subject sat at a box with a goggle-like opening at one end which supported his face while he looked into the box. The other end of the box contained a ground-glass screen in the center of which was a small plus (+) sign on which the subject fixated. So positioned, the subject was required to generate images to stimulus words while one of his eyes was continuously photographed in order to record changes in pupil size. The stimulus words were either concrete nouns such as *coffee, house,* and *pencil,* or abstract nouns like *fate, moment,* and *opinion.* In some experiments the words were presented visually one at a time on the ground-glass screen. In others, they were presented auditorily by a tape recorder. The pupil was photographed with a movie camera at a rate of two frames per second using infrared film. The task sequence always included a control period beginning, for example, with the instruction that the subject was to relax, then an experimental period preceded by instructions to generate an image to the stimulus word presented to him. In different experimental conditions the subject indicated that he had an image by pressing a key, or by saying that he had one, or no overt response at all was required. As will be seen presently, the nature of the response that indicated task fulfillment turned out to be critically important.

The consistent general findings from the various experiments can be quickly summarized. The pupil dilates during the imagery task, and the magnitude of the dilation is greater and reaches its maximum later when the stimulus words are abstract rather than when they are concrete. The effects on size but not on latency to maximum dilation are qualified by the nature of the response that indicates task fulfillment. These effects are illustrated by the following series of figures. Figure 8.1 shows one of our earliest experiments (Paivio & Simpson, 1966) in which subjects pressed a key when they thought they had generated an image. You can see that dilation is greater under the experimental than under the control condition, and that pupil size is generally larger when the words were abstract

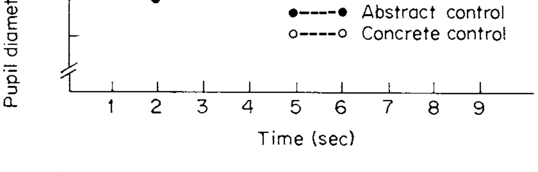

Fig. 8.1. Mean pupil size for subjects viewing abstract and concrete words under instructions to generate images to the words, and when viewing blank control slides. [Based on Fig. 1 in Paivio and Simpson, 1966.]

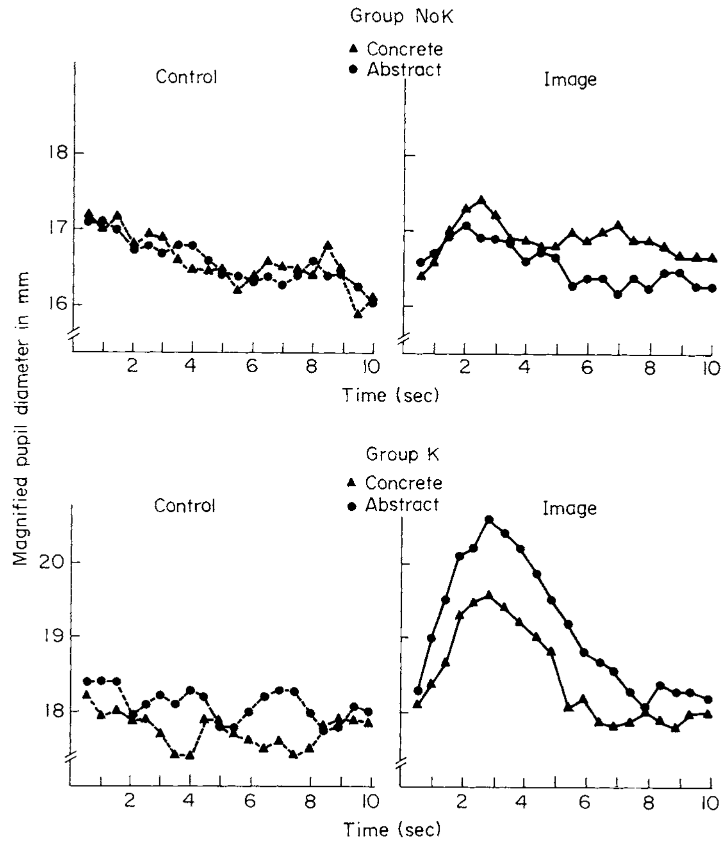

Fig. 8.2. Mean pupil diameter during control periods and while subjects were attempting to generate images to abstract and concrete words, for subjects not required to respond overtly (upper panels) and for subjects required to press a key (lower panels) when they had an image. [Based on Fig. 1 in Simpson and Paivio, 1968.]

than when they were concrete. Figure 8.2 shows the results of one pair of conditions in a later experiment by Simpson and Paivio (1968). It can be seen that, when a key press was the indicator of image arousal the results were essentially the same as in Fig. 8.1, but when the subject was not required to press a key, the pupillary reaction did not differ from the control period. The increase in pupil size and the concrete–abstract difference occurred also when task fulfillment was indicated by verbalization rather than by a key press.

Although the size effect was attenuated by the absence of an overt response, the difference in latency of the response was not. Figure 8.3,

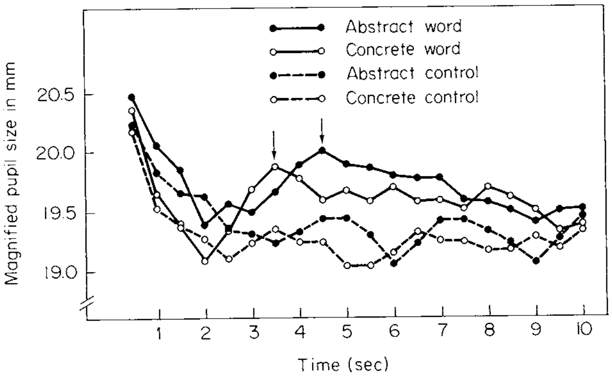

Fig. 8.3. Pupillary response curves over time while subjects were imaging to concrete and abstract words and during control conditions. Arrows indicate points of maximal dilation. [From Paivio and Simpson, 1968.]

shows the results of an experiment by Paivio and Simpson (1968) in which the subjects were not required to press a key or verbalize during the imagery task. It can be seen that the pupil nevertheless reached a maximum sooner when the words were concrete than when they were abstract.

Alternative interpretations of the pupillary findings. What do these results mean? In general they can be interpreted as an arousal or activation effect associated with the cognitive task rather than as a specific indicator of imagery per se. In this respect the findings are consistent with a large body of earlier literature showing that the pupil dilates during cognitive activity and that the degree of dilation is related to the difficulty of such activity. However, the results also extend the previous findings by showing unequivocally that the pupillary response is enhanced when an overt motor response is required to indicate task fulfillment. It becomes important, therefore, to understand precisely why the motor response has this potentiating effect.

Simpson and Paivio (1968) considered a number of alternative possibilities. One is that making an overt response required the subject to decide explicitly whether the appropriate mental state (the image) is present or absent, and such a decision increases arousal level. A related possibility, suggested also by Hakerem and Sutton (1966), is that increased activation results from motor feedback associated with the *anticipation* of making the overt response. A third alternative is that feedback from the motor response itself contributes directly to the level of activation (cf. Nunnally, Knott, Duchnowski, & Parker, 1967). Finally, the subject's arousal level may be increased because the overt response (e.g., the description of an image) is publicly observable and, therefore, exposes the subject to evaluation by the experimenter as audience. There are various difficulties with each of these interpretations but none of them could be ruled out on the basis of the evidence that we were aware of at that time.

Simpson subsequently set out to investigate the effects of some of the variables we had considered. In one experiment (Simpson, 1969) he compared the effects of a key-press response that was either related or unrelated to the preceding cognitive task, which involved pitch discrimination. The results showed a much more pronounced dilation effect when the response was relevant to the task than when the same response was irrelevant. In another experiment, Simpson and Climan (1971) measured pupillary as well as electromyographic changes during an imagery task and were able to conclude that pupillary dilation during the task could not be explained in terms of muscle activity in the effectors involved in making the response that indicated task fulfillment. These experiments suggest that feedback from the motor response itself is not an adequate explanation of the potentiating effect of that response on pupil size. In a further experiment, Simpson and Molloy (1971) used subjects who scored either high or low on a measure of proneness to audience anxiety, reasoning that this might reveal any effects attributable to apprehension about verbalizing or otherwise responding overtly in the task situation. They indeed found that high-anxiety subjects showed greater pupil size than low-anxiety subjects but the effect was specific to the time immediately preceding the subject's response. Apparently, anticipation of the verbal report was somewhat anxiety-arousing for the high audience anxious group and it resulted in a maintenance of pupil dilation for these subjects. Nevertheless, both groups showed similar pupillary dilation to the cognitive task itself, so the emotional factor was not sufficient in itself to account for the changes in pupil size that accompany mental activity.

The results of these various experiments leave decision processes as the most likely explanation of that effect. That is, before the subject can respond overtly, he must decide whether the appropriate mental state, in this case an image, has occurred, and such a decision increases arousal level and pupillary dilation. Consistent with this interpretation, Simpson and Hale (1969) found greater pupillary dilation among subjects that were required to decide in which direction a lever was to be moved than among yoked controls who were told in which direction to move the lever. The term *decision* in this context could be interpreted to mean the motor command that initiates the overt response, but this is a matter for further research.

Contribution of the pupillary data to the operational definition of imagery.

The potentiating effect of the motor response on pupil size is interesting in its own right and worth pursuing because it may be relevant to such general issues as the motor theory of thought. But have the pupillary data contributed anything specifically to the conceptualization or imagery as a mode of thinking? The answer is "yes" in at least one respect—they provide further support for the validity of a particular operational definition of the concept of imagery. I said earlier that subjects' ratings and reaction time data have indicated that concrete and abstract words differ in the ease with which they evoke sensory images. The pupillary data are completely consistent with this conclusion. That is, we can infer that the pupil dilates more and takes longer to reach maximum size with abstract than with concrete words as stimuli because it is more difficult to generate images to abstract terms. Note that this inference is justifiable despite the potentiating effect of the overt response on pupil size because the subjects responded similarly to both classes of words. Thus whatever the factors involved in making that response, it is difficult to see how they would account for the differences in the magnitude of dilation to concrete and abstract stimuli.

The time to maximal dilation provides even better validation of the word imagery concept inasmuch as maximum size was reached sooner in the case of concrete words even when no overt response was required on the part of the subject, and the magnitude of the pupillary response did not differ significantly for the two classes of words. Indeed, Simpson, Molloy, Hale, and Climan (1968) showed for three levels of word concreteness that the latency of dilation was a more reliable index than magnitude. Moreover, Colman and Paivio (1969) found that latency of dilation was a more reliable indicator of word concreteness than was another autonomic measure, the GSR. Thus the latency of the pupillary reaction seems to be particularly sensitive to the difficulty of the act of generating images to words and could be especially valuable in a variety of cognitive tasks. Thus it might be useful to combine this index with EMG recordings in the way that McGuigan (1970, 1971) has done in his investigations of covert speech. It is possible that differences in the latency of the pupillary response would correlate with covert activity in the speech muscles although no overt response is required of the subject in the imagery task. Such implicit speech activity might be picked up by EMG recordings from the speech muscles. If they are not, it would strengthen the argument that the imagery task indeed involves nonverbal cognitive activity, although it would not be an argument against a motor theory of thought. In fact, the occurrence of pupillary reactions during cognitive activity appears superficially to be perfectly consistent with the motor theory of thought. There is one difficulty, however—the ciliary muscles lack receptors to provide sensory feedback after a pupillary response. This has some interesting implications to which I will return later.

2. Imaginal versus Verbal Processes and Pupillary Dilation

The preceding discussion raises a question: Might the pupillary reactions somehow differentiate between imaginal and verbal cognition? There is no good reason why the pupillary response itself should reveal such differences, although it might supplement other behavioral indicators in a particular situation. In any case, too little has been done on the problem to suggest any firm answer. In one study, Steeves, Paivio, and Simpson (1967) investigated pupillary reactions to both the imagery task and a comparable task in which subjects were asked to generate verbal associates mentally to the same stimulus words. The study included other variables which resulted in complex interactions that are irrelevant here. The relevant point is that pupillary dilation occurred to a similar degree during both the imagery and the verbal associative tasks.

In another experiment, Colman and Paivio (1970) monitored pupillary activity during a paired-associate learning task involving nouns as items. The abstractness–concreteness of the nouns was varied and the subjects were asked to learn the pairs under standard paired-associate learning instructions, or using imagery or verbal mediators. In the case of the imagery mediation condition, the subjects were told to try to associate each pair by generating a compound image that incorporates the objects or events suggested by the nouns, and in the verbal mediation condition they were told to form phrases or sentences that linked the two nouns. The performance data showed that learning was better under the two mediation conditions than under the standard paired-associate learning instructions, at least when the stimulus nouns were concrete. This is generally consistent with earlier research on mediated learning (see Paivio, 1971). The most interesting feature of the data for present purposes is that the pupillary reaction differed for the different conditions over trials. The mean pupillary diameter is shown in Fig. 8.4 for each of four recall trials, during which the subjects were presented each of the stimulus words in turn and were asked to recall the responses. The figure shows that pupil size decreased systematically over trials for both the imagery and verbal mediation subjects, but remained at a high level over trials for the subjects who were not given the mediation instructions. These results are consistent with the view that the task was more difficult and the pupil, therefore, dilated more under the condition that involved no mediators as associative aids. I should mention also that the different groups performed equally well by the fourth trial, so the differences in pupil size are not simply correlated with learning performance. They suggest that

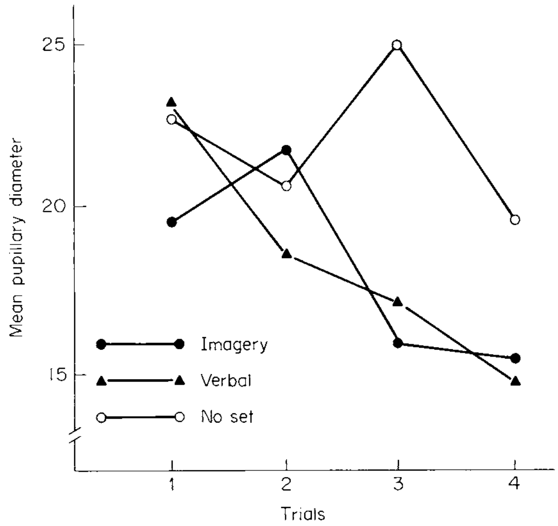

Fig. 8.4. Mean pupillary diameter in millimeters (magnified approximately ×4) during four paired-associate recall trials, for subjects learning under imagery, verbal, and no mediation instructions. [From Colman and Paivio, 1970.]

the subjects had to work harder throughout the task when learning under standard conditions than when they had a specific mediational set to follow. In this respect, the physiological measure appears to be more sensitive than the performance measure to the cognitive demands of the learning task. In addition, larger pupil size was associated with word pairs with abstract stimulus members. This also is consistent with the performance data, which showed that such pairs are more difficult to learn than ones with concrete stimulus members.

Up to this point, then, it can be concluded that the pupillary response can be an informative addition in cognitive tasks, but in our hands at least it has not permitted us to differentiate clearly between verbal cognitive processes and nonverbal imagery. The possibility remains that some of the findings in fact represent effects mediated specifically by imagery and that our procedures were simply too insensitive to detect when this was the case. The final section of this paper deals with our attempts to find more more sensitive procedures.

3. Pupillary Reactions and the Content of Imagery

The pupillary studies to be discussed in this section directly investigated the possibility that pupillary reactions might reveal something specific concerning the nature of imagery. Earlier I mentioned a comment by Jaensch to the effect that eidetic children showed differential pupillary reactions when imaging bright and dark objects. This observation, if reliable, has remarkable implications. It implies either that appropriate pupillary reactions can be directly conditioned to verbal stimuli as a result of their association with bright and dark objects, or that imagery (itself perhaps a product of conditioning) is a central mediator of the reaction. The direct conditioning interpretation runs into the problem that pupillary conditioning has been difficult to demonstrate with changes in light intensity as the unconditioned stimulus (Young, 1958, 1965). In addition, Loewenfeld (1966) has recently argued that "all psychologic and sensory stimuli, with the exception of light, dilate the pupil and none of them contract it [p. 294]." Such problems raise doubts concerning the reliability of the phenomenon reported by Jaensch unless a mechanism other than conditioning is postulated. However, successful pupillary conditioning with light as the UCS has been reported in recent studies in the Soviet Union (see Hartman, 1965, p. 100; Sokolov, 1963), so the occurrence of appropriate conditioned reactions to words denoting bright and dark objects could not be entirely ruled out; or so it seemed to us at the time that we became interested in the problem. Alternatively, the possibility that conditioned reactions could be mediated by some central process such as imagery has been suggested by a number of investigators (Beritoff, 1965, p. 7; Mowrer, 1960, p. 171; Sheffield, 1965, p. 315), and such mediation may be the basis of the phenomenon described by Jaensch.

In any case, Paivio and Simpson (1967) investigated the general reliability of Jaensch's observation, with a view to exploring the alternative hypotheses in later studies if the effect could be obtained. Rather than using eidetic children, we used university students who differed in their imagery ability according to scores on spatial manipulation tests and questionnaires. Their task was to attempt to generate memory images of pictures of black or white objects to which they had previously been exposed. Their pupils were continuously photographed during the task. The task also included control periods during which the subjects presumably were not imaging. The specific sequence of events was as follows. A black or white picture was shown for 10 sec. This was followed by a 10-sec control period during which the subject fixated on an X on the screen while attempting to keep his mind a blank. Then the printed letter R was shown, which was the cue for the subject to try to generate a mental picture of the photograph he had just seen. We also included a small control group that were not given the recall instructions.

The results showed no effect attributable to the imagery ability variable, but they did suggest that differential dilation occurred during the imagery task. The findings are shown in Fig. 8.5. The left panel of the figure shows the results for the control period for the experimental group while the right-hand side shows the results for the recall period for that group. The lower two curves represent the pupillary reactions of the control subjects not given the recall instructions. The upper two curves in each case are the results for the experimental subjects. The control subjects essentially showed no differential effects, simply a decrease in pupil size during the periods corresponding to the control and recall intervals for the experimental subjects. During the first part of the control interval, the experimental subjects showed slightly greater pupil size after viewing the black stimuli than after white stimuli, which simply reflects a carry-over effect of the stimulus itself. By the end of the control period at time blocks C and D in the figure, the pupil size did not differ for the two stimulus conditions. During the recall period, shown in the upper two curves at the right of the figure, pupil size stayed at a high level throughout the recall period when the subject was recalling black objects, whereas a significant reduction in size occurred when they were recalling white objects. Thus, although the results did not show constriction relative to a neutral base

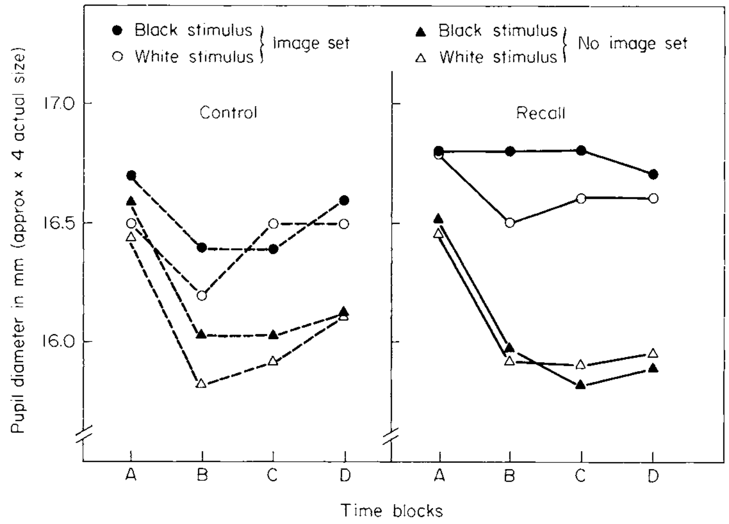

Fig. 8.5. Mean pupil size over time blocks for (a) an image-set group ($N = 36$) under control conditions and while attempting to recall black and white stimuli, and (b) for a group ($N = 6$) not given the recall instructions. [From Fig. 3 in Paivio and Simpson, 1967.]

line, they did show differential amounts of dilation which in general appeared to be consistent with Jaensch's observation. The fact that absolute constriction did not occur during recall of white pictures might simply mean that the pupillary response reflected a tendency toward constriction superimposed on general dilation associated with the difficulty of the imagery task.

An alternative possibility is that the results were an artifact of our procedure. It is known that pupillary reactions to changes in illumination are elicited most readily when the stimulus falls on a very small area of the retina including the macula. In the case of our experiment, during the recall of black pictures the subject's attention may have been somehow directed to black portions of the slide (e.g., the letter R which cued his attempt to generate images) whereas during recall of white pictures he attended to white parts of the slide (cf. Loewenfeld, 1966; Woodmansee, 1966). Such differences in attention could result from implicit verbalizations during attempts to recall the stimuli. For example, when trying to recall a black stimulus a subject may say to himself "black square" and this could mediate his attending to a black part on the recall slide. Such a possibility as well as other problems could be better controlled by the use of auditory rather than visual cues during control and recall periods while maintaining constant, homogeneous illumination of the visual field. This is precisely what Simpson and I did in another experiment, with the result that we failed completely to replicate our finding from the first experiment. We were forced to conclude, therefore, that differential pupillary reactions do not occur reliably when subjects imagine white or black objects.

It could be argued of course that we failed to demonstrate the phenomenon reported by Jaensch simply because we did not use eidetic children as subjects. While our sample included people with high-imagery ability according to certain measures, they were not tested for eidetic imagery according to the criteria suggested by Haber and his associates (Haber & Haber, 1964; Leask, Haber, & Haber, 1969). The imagery that eidetikers report apparently differs qualitatively from that reported by noneidetikers, particularly in regard to its vividness and its perceptlike localization "out there" rather than within the individual, and it may be that the qualitative differences are necessary in order to demonstrate pupillary constriction under instructions to image bright objects. Thus the question remains open in a strict sense, although I must confess that I am skeptical about the possibility of obtaining positive findings in this area. This view is reinforced by the fact that Barber (1971) recently reported a failure to get differential pupillary reactions to hypnotically induced images of bright and dark objects.

If such pupillary reactions were in fact demonstrated, it would implicate classical conditioning as the mechanism responsible for the effect. It is relevant, therefore, as well as interesting in its own right, to consider experimental attempts to condition pupillary constriction with light as the UCS. Recall my earlier statement that successful conditioning has been reported in Soviet literature, but the best-controlled studies in the United States (Young, 1965) have failed to do so. Again, however, certain methodological differences left the issue open. The American studies have generally used sound as the condition stimulus, whereas Sokolov (1963) reported positive results with temporal duration as the CS. Specifically, Sokolov presented his subjects with alternating periods comprised of 4 sec of darkness interspersed with periods of light. After repeating the cycle a number of times, the dark period was unexpectedly increased to 10 sec. Under these conditions the one subject for whom Sokolov reported data showed an anticipatory constriction of the pupil approximately at the point where the light had previously occurred, namely, 4 sec after dark onset.

Without having any idea why differences in the CS should be crucial, Frank Colman and I attempted to replicate Sokolov, following his procedure as precisely as we could, and using a larger number of subjects. Without burdening you with all the details, I can report that the results were unequivocally negative. Thus the results of the imagery research as well as our conditioning experiment are completely in agreement with Loewenfeld's (1966) assertion that psychologic stimuli can only dilate the pupil, they do not contract it. Why this should be the case is an interesting puzzle that challenges conditioning theories in particular. Young (1965) suggested that pupillary reactions cannot be classically conditioned with changes in illumination as the UCS because sensory feedback from the response is essential for conditioning to occur and the ciliary muscles that control pupil size lack sensory receptors that could produce such feedback. This seems to be an argument against a central (S–S) interpretation of sensory preconditioning and centralist interpretations of thought, both of which assume that at least some associations can be formed within the central nervous system without any motor feedback. I mention this just to indicate that the kind of research I have been discussing raises some fundamental issues concerning the mechanisms of learning and thinking, but I am unable to add anything that would clarify those issues on the basis of the research reported.

The Discussion of Dr. Paivio's Paper

LED BY DR. CHARLES OSGOOD
University of Illinois

Osgood: Both Dr. Paivio and myself are a couple of molars in what seems like a sea of moleculars. Our concerns have been to try to get help from psychophysiology—and in my case from psychophysiologists, like Dr. McGuigan—in trying to resolve some of our own problems; it is not so much to just extend knowledge of psychobiology, or psychophysiology, per se.

Yesterday, we had some interesting discussion about how psychophysiologists were reviving some of the unidimensional mentalistic concepts, e.g., attention, arousal, etc. It seems to me that Dr. Paivio, and I in my own talk later, will be going even further back to concepts of imagery, meaning, and even William James' ideomotor action, i.e., images of action. This is old stuff, but, like some kinds of bourbon, it does not seem to lose its flavor.

As most of you who have read the work know, Dr. Paivio's revival, in contemporary psychology, of the role of imagery—in learning, in memory, and in many other fields—is one of the more impressive sets of programmatic researches of our present psychological generation. He has, at the behavioral level, clearly put imagery back into contention as a significant function, in many of the processes where we would have never even thought of it before.

Dr. Paivio and I have had, over the last couple of years, a rather voluminous interchange of correspondence about our agreements and disagreements with regard to theory. I just want to point out a couple of things which raise questions.

The first one concerns Dr. Paivio's statement, or assertion, that imagery is essentially a simultaneous, parallel kind of processing of information; whereas verbal behavior, or linguistic processing, is essentially sequential. I would like to point out that imagery, itself, can well be a sequential process. And certainly, when you look at one of the fundamental defining characteristics of human languages at both phonemic and semantic levels, you have simultaneous bundles of components, i.e., phonetic and semantic components, which are in parallel; literally, these are simultaneously excited and are operating as a whole pattern. I'll come to this later myself.

The interesting thing is that these simultaneous processes have a clear, coded componential nature, i.e., they function like a set of components, at both the phonemic and the semantic levels; this is an extraordinarily efficient system. I would suggest that one of the main *differences* between imagery and meaning is the componential nature of the verbal semantic system, as compared with imagery.

This leads to very interesting problems. Dr. Paivio talked about (and the evidence certainly supports him) the role of imagery in recall; somehow images must be stored. There is a great deal of evidence about storage in terms of meaning. In fact, most of the recent evidence makes it clear that storage in long-term memory is itself, to a large extent, a function of the very efficient componential kind of system I have just noted. But I find it awfully hard to imagine just how images are "stored." My argument would be that images are not stored; rather, at some point, perhaps in delayed processing, they are put into a componential coding system, which is probably the same as that used for meanings. There is good evidence that perceptual and linguistic *signs* share the same representational (semantic) systems. Then those processes can, in turn, recreate the image, on a reduced cue, feedback basis—thus an image is a redintegrated perception (to use another ancient notion).

There is, I think, a real problem in Paivio's theory and I do not think, in my reading of his work, that it has been touched on yet. If you do really have independent systems of imagery and meaning, at higher levels of the nervous system, and if they are completely independent in terms of not only the mediating activity but also in terms of memory and storage, then the problem is, how can images as wholes be stored? Images, as far as I can see, do not have any comparable componential kind of character, efficiently broken down into features which can be distinctively combined, etc. This is an interesting problem, Dr. Paivio, and you might like to comment on it.

Another problem I find most puzzling is how imagery and meaning are interrelated. As Dr. Paivio clearly indicates, he believes that they *are* interrelated. Now I will take an extremely strong position—one that I probably do not exactly believe, but, just for the sake of argument, I will assert it for the moment. This argument would be that you always have coded (semantic) central storage and that imagery is always a dependent event, centrally innervated *from* stored meaningful material. It is one kind of re-creation, if you will, of something very much perceptionlike, but from central innervation, rather than from externally initiated perceptual integration; we call it *perception* when it is externally excited, but *imagery* when it is centrally excited. That is the strong case.

This leads to yet another problem—the relation between perception and image. Usually, if the perceptual integrative process is clearly dependent upon external stimulation, e.g., looking at an object or a picture, we do not call it *image*—we call it *perception*. But then we have the problem of the initiation of imagery: what is it that initiates images, as in dreaming, or as when asked to imagine what your living room looks like? Clearly, the input here may be external, but it still requires the central contribution—the meaning of your living room, etc., in order to somehow initiate the imagery. In fact, the very early study of Perky (1910) that Paivio referred to showed that, if you had subjects striving to create a central image of a banana on a screen, and a very *faint* input picture of a banana was projected, the subjects would typically say, "Oh, I have a marvelously clear image." Apparently, it is very difficult—subjectively at least—to distinguish between what is a very faint, externally excited, perceptual integration, which we call perception, and what normally would be considered a very clear and sharp image. So I am suggesting that, really, imagery and perception involve the same basic level or system—perceptual integration—the difference being initiation, whether through the external projection system or via feedback from the more central system.

Open Discussion

Paivio: With regard to sequential versus parallel processing, the language code (words, or their subunits, and how they are organized) is a sequential operation. The process, which Dr. Osgood considers to be simultaneous bundles, is aroused as simultaneous bundles by the verbal input. The bundles are in the same class as images, in this sense: the subject first sees the word, and the word matches some kind of internal representation in the speech center; other processes are then aroused which are the semantic, emotional, Osgood's EPA components, and imagery as well. Imagery differs from language in that imagery is a parallel rather than a sequential processing operation: Think of the phrase, "white horse." Now imagine the referent—the "white" and the "horse" are together as one, but the two words are sequential. In contrast, consider another pair of units that are, like white horse, associatively linked: "basic theory." You can't unitize basic theory into a simultaneous image, as you can white horse. Basic theory function as two units. The difference is related to the imagery characteristics of the items. So one pair creates a parallel, simultaneous representation of some kind, and the other does not. I strongly agree that imagery and perceptual processes are similar, probably involving the same channels. With regard to imagery and meaning, our differences are a matter of how one views meaning. "Meaning" is a multimeaning word, and I see imagery as one kind of meaning reaction.

Audience: Could you elaborate on the tests of spatial manipulations which you used to classify people as vivid imagers?

Paivio: Of course they are not measures of vividness, but measures of spatial manipulation skills, e.g., The Minnesota Paper Form Board, Spatial Relations, Thurstone's Flags Test, items from Guilford's classification of figural and transformational abilities in his work on the structure of the intellect.

Audience: Have you used the Betts test of vividness?

Paivio: Somewhat. It is a vividness test, patterned after Galton's original "breakfast table" questionnaire. It hasn't paid off well, in Sheehan's research in Australia, nor in our attempts. The objective ability tests seem to be better predictors in some situations than the vividness tests.

Dr. Richard Blanton (*Vanderbilt University*)*:* Regarding Dr. Osgood's statement about the regeneration (recovery) problem, and with regard to both imagery and perception, Hebb once said that quite often when you ask people to verbally reconstruct their living room, they will do it from a standpoint from which they do not ordinarily perceive it. This suggests that the reconstitutional process often produces a different product than the original perception, and raises the old question of the relationship between relaxation and the vividness of the imagery. Relevant here is Dr. Foster's statement, yesterday, that we have done very little with hypnogogic states and with reproduction of imagery under various kinds of elicitation conditions. Have you some thoughts on that?

Paivio: We have more generally been concerned with the functions of our postulated system in relation to behavior than in making the fine distinctions among different types of imagery. Perhaps qualitative differences in images can be made, perhaps there are none, or perhaps they are simply defined by the time and kind of situation in which they occur. There are images of memory, where you reconstruct something you know, that occur in dreams (very bizarre forms) and in waking. But objectively, we know very little, or almost nothing, of those images; and you cite merely Hebb's introspection about it. I have anecdotes similar to Hebb's; for example, when I imagined my kitchen, I had the startling experience of realizing that I looked through the house from the kitchen, through the living room, into the garage on the other side. This is bizarre, but I do not believe it is given by anything but my sensory experiences associated with the various components of my home.

Audience: It suggests, though, the reconstitution of a recreative kind of process, rather than a template, a picture.

Paivio: To be sure. Many people have said such things, but I don't believe they really understood the distinction between static and constructive–dynamic images. Surely today we must get away from the idea of a static memory of a still picture of a situation. Memory is a dynamic and constructive process, but we don't know how images are stored. We don't know how words are stored, either. I am absolutely sure that we store information about nonverbal situations; you can be convinced by remembering familiar things—such memories aren't verbal, but there is a linkage. This is one of the most interesting questions to which the psychophysiologist could address himself, viz., how does the interrelationship between verbal and nonverbal memories occur? I believe that they can be independent, since you can affect one without the other being involved. We can also show experimentally that they are interconnected because of the kinds of transformations that I was talking about. Even the introspective evidence is compelling on the point. But we haven't got the vaguest idea of the way that information is stored, and still less than none about the verbal–nonverbal interconnections, other than they perhaps go through the corpus callosum. How the information is coded and stored is a complete mystery.

Dr. Rechtschaffen, yesterday, talked about the lack of information concerning the nature of dreams. Dreams, images, and thoughts generally are unexplained by any current theories. Here lies an enormous challenge for psychology, psychophysiology, and neuropsychology.

Dr. Michael Seitz (*University of Pittsburgh*)*:* You mentioned that your work focused on one eye. Have you done a study with both eyes?

Paivio: No, not with the pupillary response.

Seitz: My question, perhaps, anticipates Dr. Sperry's talk: If you gave verbal input instead of visual, would there be a differential dilation between the right eye and the left eye, versus the right hemisphere and left hemisphere?

Paivio: I doubt that would happen. You get consensual dilation, for example, with the stimulation of one eye only; the other eye, depending on the stimulus, will respond similarly. I would be surprised if you get differences, unless there is some kind of neurological damage.

Dr. Louis Aarons (*Department of Mental Health, Chicago*)*:* Do you really believe that language and image systems differ as far as sequential and parallel processing are concerned?

Paivio: Well, it is not a matter of belief; it is a working hypothesis.

Aarons: Yes, but there is evidence on both sides that, by varying the dimensions and instructions, you can make pairs of words unified, e.g., "cruel-kindness" is unified to me.

Paivio: "Cruel-kindness?" Abstract phrases like that have been studied and the fact is that they function like two units in memory. With regard to parallel versus sequential processing, Dr. Osgood mentioned that images are sequential. I think we have to distinguish here between the way information is organized in the system—in memory, e.g., and the *total processing* of it; there could be serial aspects of processing during input to output. Most processing of visual information is serial at the perceptual level, because of the limitations of the output channels. So if I describe what is in my visual field, I fixate on different points, but the output, of course, will be one at a time in the description. This serial output occurs even though the information exists in parallel, in the sense that it's all simultaneously available to my retina; and how I process the information serially in outputting it depends on what I attend to. And that is a problem of set, or motivation, or some other factor than the layout of that information.

Audience: What about the image of, "Jack jumped over the candlestick?"

Paivio: There *are* sequential images, provided that you have learned the sequence of activity related to it; so that "Jack jumped over the candlestick" involves a learned series. I am not saying that imagery can't go on continuously, but that this probably is created by a motor aspect to which the imagery is linked; and the perceptual aspects and information, at any point in time, are synchronous, so that "Jack jumping over the candlestick" is more synchronous than the words, "Jack . . . jumped . . . over . . .," etc. If you compress it in time, it seems to be more or less simultaneous in the language aspect. You can get effects in imagery which behave like sequential information if they are tied to a verbal sequence, as in the use of the "one, bun; two, shoe; . . ." technique; but the sequence here is created by the verbal aspect to which the imagery is tied. "One, bun" creates the image of "bun, two, shoe." The rhyme and the numerical sequence is sequential; the images themselves are not. And we have shown, using our pictorial materials, that discrete items of information, with no natural action sequence, are not remembered sequentially, unless there is some kind of motor or verbal component. Discrete verbal units, however, *are* well-ordered sequentially, even if they don't have a natural high transitional probability between them.

Dr. Paul Woods (Hollins College): Would you outline again the theoretical implications of the fact that the pupillary response is greater to abstract than to concrete words?

Paivio: The interpretation is in terms of activation or arousal—it is more difficult to generate images to abstract words, because the interconnection between an image and a verbal system is either weak or absent.

Dr. David Johnson (Sweetbriar College): In one of your studies, using a paired associate task, you had three groups of subjects: One group was told to use an imagery type of mediator; another group, the verbal mediator; and the third group was given no set at all. Were the data obtained for recall performance?

Paivio: Yes.

Johnson: They are typical unloading functions.

Paivio: Yes. The unloading occurs more easily for the mediation group, as shown by the decrease of the pupil size.

Johnson: But what assurance did you have that the no-set group learned as well as the other two?

Paivio: They didn't; but by the fourth trial, the learning differences between groups were minimal. In studies like this, you typically get a convergence over trials for the mediation and control groups, so that after three or four trials, there really is minimal difference. Regarding the unloading hypothesis, while the performance of all groups improved dramatically over four trials, the pupillary data reflected the improvement only in the case of the mediation-set group.

Johnson: That's what was puzzling to me, but I certainly wouldn't argue that the mediation would help in the learning rate. However, given that the three groups had learned at the same level, it is hard for me to see how the mediator helps to unload.

Paivio: I think you can learn at the same level with greater or lesser effort. You can really learn to use imagery devices—mnemonic pegs, e.g., with consummate ease, to remember enormous amounts of information. Using rote repetition to learn the same amount of information in a larger time period does not seem as easy. This is subjective, because nobody has systematically asked people about the ease of the experience; anecdotally, this is the way it seems, and I think that the pupillary data are interesting in this respect.

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