Chapter 8

An Integrated Analysis of the Structure and Function of Behavior: Aging and the cost of dividing attention*

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Introduction

Basic processes of operant conditioning are studied most often in the animal laboratory, and the results have had important implications for the world of human affairs as well as for theories of behavior (Myerson and Hale, 1984). However, direct investigations with human subjects are not only desirable but also quite possible (Baron and Perone, 1982). The purpose of this chapter is to examine some complex instances of stimulus control as they have been revealed by the laboratory study of human behavior. Our discussion of stimulus control uses the language and concepts of behavioral (operant) psychology. But our analysis also draws heavily from two areas of inquiry more traditionally allied with cognitive theory. The first is that of divided attention. Although processes of attention have not been ignored completely in the study of operant conditioning, the concept of attention plays a less vital role than in the study of information processing. The second area pertains to the psychological changes that accompany advancing age. With rare exception, investigations of the performance capabilities of older adults have been conducted within cognitive

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Stimulus control and attention

As the term suggests, stimulus control refers to the extent to which antecedent stimuli determine the strength of a response. The important features of this phenomenon have been identified in numerous experiments conducted in the animal laboratory. A primary role is played by differential reinforcement, that is, a higher probability of reinforcement in the presence of one stimulus relative to another (discrimination training). Stimulus control is manifested by higher response rates in the presence of the stimulus associated with the higher probability. Control also depends in important ways upon features of the discriminative events. Not surprisingly, control develops more readily when stimuli have markedly different characteristics (as when a rat is reinforced for pressing a lever when the chamber is illuminated but not when it is darkened), than when the two are more similar (different levels of illumination). Although stimulus control is most readily accomplished by explicit discrimination training, the procedure of simply reinforcing responding in the presence of a single stimulus may suffice. This outcome is seen when single stimulus training is followed by extinction tests with other stimuli; responding characteristically declines as the test stimuli are made more disparate from the training stimulus (stimulus generalization).

Stimulus control is a reliable aspect of operant conditioning. For this reason, instances when control appears to fail are of special interest, as when a stimulus unmistakably present during the reinforcement of a response fails to control responding. It is here that the concept of attention often is invoked. The issues are illustrated by Jenkins and Harrison's (1960) often-cited study of auditory generalization in the pigeon. In their procedure, key pecking was reinforced in the presence of a particular tone (single stimulus training), and then the birds were tested with a range of tones (generalization tests). Similar procedures with visual stimuli (colored lights projected on the response key) are well known to produce decremental generalization gradients. When tones were the stimuli, the surprising finding was that gradients were essentially flat, indicating that the training stimulus had not assumed differential control. Moreover, there could be no question about the ability of the birds to discriminate the tones because decremental gradients were found after discrimination training (responding was reinforced when the training tone was on but not when it was off).

An account of these and similar findings in terms of the concept of attention rests on the assumption that not all aspects of the stimuli associated with reinforced responding necessarily are attended to. In the case of pigeons, for example, it may be the case that auditory events do not ordinarily serve as effective stimuli. Differential reinforcement compels attention to auditory characteristics of the environment, and thus allows stimulus control to develop. However, various writers have urged caution in the use of attention to explain instances of deficient stimulus control (e.g., Rodewald, 1979; Terrace, 1966). Under some circumstances, attention can be regarded as an actual response that can be directly measured, as when the organism orients itself toward some stimulus other than the one associated with reinforcement. But usually, the only basis for determining whether or not the organism has paid attention is whether stimulus control has been accomplished. Without independent evidence, the concept of attention is better regarded as descriptive than explanatory. This is the way we will use the term in our consideration of divided attention: To describe (rather than explain) instances when the control exerted by concurrent stimuli is less than the sum of the control exerted by these stimuli presented individually.

Age differences in attention

A widely accepted conclusion is that attentional processes decline with advancing age. Such changes have been viewed within cognitive theories of aging as important contributors to a range of other deficits, including those in the areas of memory, psychomotor performances, and perceptual functioning in general (Burke and Light, 1981; Craik, 1977). Regardless of theoretical framework, one can see the value of including age as a variable in the study of attention. In addition to gaining interesting information about adult development, the analysis of stimulus control is expanded when the procedures include individuals with different discriminative capabilities.

There is an extensive literature on cognitive aspects of age–attention relationships (see Kausler, 1982, for a review). In the present discussion we focus on studies concerned with the phenomenon of divided attention, that is, performances in situations in which the individual must deal simultaneously with two or more stimuli. Operant psychologists have not shown much interest in divided attention (and especially not in whether there are age differences in this regard). Divided attention, however, implies a process of competition, and response competition has been a matter of considerable theoretical interest within operant psychology, particularly in connection with responding under concurrent schedules of reinforcement (de Villiers, 1977). Thus, analyses of divided attention in terms of a competition between responses may serve as a bridge between cognitive and behavioral conceptions of stimulus control.

The procedures used by cognitive psychologists to study divided attention are diverse, and there is controversy about the proper interpretation to be placed on
the results (see Somberg and Salthouse, 1982). However, a characteristic outcome may be seen in research on dichotic listening. Subjects wear stereo headphones, through which pairs of auditory stimuli (e.g. digits) are presented simultaneously to the two ears (the two channels). Following the last pair, tests of memory are conducted, first for one channel and then for the other. Research comparing adults of different ages has indicated that older adults are not as accurate as younger ones on this task, but the extent of the deficit depends on details of the procedure. For example, if the subject is free to determine which channel will be reported first, the age-related deficit primarily involves the second channel. When the order of testing is placed outside the subject’s control (and not announced until after the sequence is completed), deficits are found in both channels.

These sorts of findings have been used to support the contention that older individuals are particularly deficient in situations requiring the simultaneous processing of stimuli from different sources. When the tasks are simple, available resources may be sufficient to allow efficient performances of the simultaneous activities. But when increasing demands are placed on the capabilities of the individual, attention paid to one task must be at the expense of the other. In dichotic listening, for example, the attention paid to one channel leaves insufficient residual capacity for effective processing of the other channel. Thus, from a cognitive standpoint, deficient performances by older individuals are seen as the consequence of either reduced processing resources or a difficulty in allocating these resources.

**Competition and divided attention**

**A behavioral description**

From a behavioral standpoint, divided attention can be viewed as the competition between different stimuli for control. Consider the simple case in which two aspects of the environment (either two stimuli or a single stimulus with two dimensions) compete for control of behavior. Within this framework, the term divided attention describes those situations in which strong control by one stimulus reduces control by the other. This relationship is exemplified by Reynolds’ (1961) study of attention in the pigeon. Following discrimination training with a red triangle and a green circle, responding came under the control of the form of the stimulus or its color, but not both. For example, during generalization tests, one pigeon responded exclusively to an achromatic triangular form and another to the color red.

It may be seen that an account of divided attention in terms of relative degrees of stimulus control requires the assumption of a tradeoff. Increased control by one stimulus produces weakening of control by a concurrent stimulus. If, in addition, the total amount of stimulus control possible in a given situation is assumed to be finite, the relationship may be stated in the following mathematical form:

\[ S_1 + S_2 \leq A \]

where \( S_1 \) and \( S_2 \) are the amounts of control exerted by the first and second stimulus, respectively, and \( A \) is the maximum amount of control possible in a given situation. An important feature of equation 8.1 is that the values of \( S_1 \) and \( S_2 \) may increase independently until their sum equals the limit set by the value of \( A \). Beginning at this point, there must be a linear tradeoff in stimulus control, that is, a further gain in control by one stimulus must be accompanied by a loss of equal size by the other stimulus.

The assumptions of a finite attentional capacity and a linear tradeoff have been described in the behavioral literature as ‘the inverse hypothesis’ (Thomas, 1970), and may be found in Mackintosh’s (1977) effort to deal with divided attention in behavioral terms. But it also is the case that these assumptions are prominent features of cognitive models where they define ‘the principle of complementarity’ (Eysenck, 1984; Norman and Bobrow, 1975). Almost all recent cognitive models of attention, either explicitly proposed or incorporated into information processing systems, appear to contain the assumption that attention is either a resource shared among different activities or the mechanism for allocating available resources (e.g. Kahneman, 1973; Norman and Bobrow, 1975; Schneider and Schiffrin, 1977). Thus, despite major differences in language, research strategies, and avowed goals, both behavioral and cognitive views of divided attention rely heavily on the notion of competition. Depending on theoretical predilection, stimuli may be said to compete with one another for the control of behavior or for the allocation of processing resources.

We noted above the common assumption that tradeoffs in stimulus control are linear. Such an assumption, however, is by no means a necessary feature of models of divided attention, and other relationships can be envisioned (Navon and Gopher, 1979). In later sections, we present evidence showing that when simultaneously presented stimuli compete for control, outcomes can be characterized by a range of possible tradeoffs, including nonlinear as well as linear ones.

**The attention operating characteristic**

The recently proposed concept of the attention operating characteristic (AOC) represents an important advance in determining the nature of the competition when attention is divided. Working in the information processing tradition, Sperling and Melchner (1978) developed this method as a quantitative description of the competition between stimuli for processing. But the AOC also has relevance for behavior analysis when the issues are recast in terms of competing sources of stimulus control.
The concept of the AOC and the procedures for determining it can be described using the data reported by Sperling and Melchner (1978, Exp. I). The subjects observed a compound stimulus consisting of an inner and an outer array of letters, each of which included a numeral (target) that the subjects tried to identify. Division of attention between the arrays was manipulated through instructions. Under different conditions the subjects were told to vary the distribution of their attention: Under one condition to attend to one array to the exclusion of the other (undivided attention); under another to attend mainly to one ('give it 90 per cent of your attention'); and finally, to attend equally to both.

To determine the AOC, control by one stimulus is expressed as a function of control by the other. Figure 8.1 shows the outcome of such an analysis for the two subjects in Sperling and Melchner's study (to simplify the present discussion, we averaged multiple replications, and normalized values by representing them as proportions of detections in the undivided condition). The resulting functions reveal a reciprocal relationship in the control exerted by the two stimuli, in that decreased control by one stimulus was accompanied by increased control by the other.

The dashed horizontal and vertical lines in Figure 8.1 correspond to performances under conditions of undivided attention for each of the stimuli. Thus, the lines demark the maximal control that can be achieved, and the enclosed space the range of possible performances. Of special significance is the relation of values within the AOC space to the point at which the two lines intersect (upper right-hand corner), the 'point of independence' (Sperling and Melchner, 1978). This point designates the outcome when the two stimuli do not compete, in other words, the limiting case in which both tasks can be performed simultaneously as well as they can be performed singly. Values in other parts of the AOC space are indicative of the cost of divided attention—the extent to which performances decline relative to conditions of undivided attention.

The AOC function itself is represented by a line fitted to the values plotted within the AOC space. There are various ways that this might be done (Sperling and Melchner fitted straight lines), but when attention is divided between two similar tasks, a curve described by the following equation seems well suited:

\[ S_1 + S_2 = 1 \]

where \( S_1 \) and \( S_2 \) are normalized measures of stimulus control. The functions shown in Figure 8.1 are of this form and were fitted by an iterative procedure that adjusted the value of \( a \) until a maximum proportion of the variance had been accounted for.
Somberg and Salthouse (1982) proposed a method of quantifying the cost of divided attention using the difference between the total area of the AOC space and the area bounded by the AOC function. This expression of cost may be seen in Figure 8.2 as the cross-hatched area that falls above the function in the right-hand corner. With AOC functions of the form of equation 8.2, it may be shown that the area corresponding to divided attention cost is equal to $1/(1+a)$. Equation 8.2 has the advantage that it may be fit to data using only one free parameter. Moreover, the value of $a$ leads directly to an index of the interference between concurrent tasks.

The value of the divided attention cost index depends on the extent of competition between the stimuli. Figure 8.3 gives a summary of values associated with various positions of the AOC function. When the cost index, $1/(1+a)$, is close to 0.0 both tasks can be performed simultaneously as well as either one alone. With increases in the cost from 0.0 to 0.5, the AOC assumes a convex form (similar to the results of the Sperling and Melchner study) whose curvature decreases as the intermediate value of 0.5 is approached and a linear tradeoff is reached. Indices exceeding 0.5 are associated with a series of concave functions. As the cost index approaches 1.0, control by one stimulus increasingly precludes control by the other, and in the limiting case, interference between the tasks is so profound as to prohibit performance of either one.

**Age and the AOC**

Although analyses in terms of AOC functions have considerable potential for the study of aging, they have rarely been used in this way. The value of the approach may be seen in an experiment by Somberg and Salthouse (1982) which extended Sperling and Melchner's procedures to include comparisons of older and younger adults (57–76 yrs versus 18–23 yrs). As before, different divisions of attention were accomplished through instructions. Depending on the condition, subjects were told to devote their attention in various ways to the two arrays (exclusively to one or the other, equally between the two, or 70 per cent to one array and 30 per cent to the other), and to report whether or not a target had appeared in each array. A new procedure was that subjects also were told that they would be paid for correct responses according to the way attention was to be divided. For example, when 70 per cent was to be directed toward the inner array and 30 per cent to the outer array, correct inner and outer array reports were worth 0.7 cents and 0.3 cents, respectively.

Figure 8.4 is a slight modification of the AOC analysis reported by Somberg and Salthouse (we normalized their group averages and fitted the functions using the procedures described above). The AOC functions for their older subjects are virtually identical to those for a young adult comparison group; according to our analyses, the cost indices were 0.463 and 0.460, respectively. Also apparent is that the values tend to be positioned along the negative
diagonal of the AOC space, indicating that the tradeoff, although slightly convex, was nearly a linear one. Thus, this experiment found that regardless of the individual's age, improved performance of one task resulted in a nearly equal loss of proficiency in the other.

The fact that payment was made contingent on correct responses in this experiment brings it more closely in line with studies of operant conditioning variables. Cast in operant terms the results might indicate that increases in the relative rate of reinforcement associated with one array resulted in increased stimulus control by that array, as well as in approximately equal decreases in control by the alternate stimulus. But various aspects of the procedures make it difficult to be certain about the events actually controlling behavior. The reinforcers were not collected until after the experiment, and feedback was not provided following each response. These considerations suggest that behavior may have been under instructional rather than reinforcement control (Baron and Galizio, 1983). A different problem is that the data were averages of groups of subjects given brief exposure to the procedures rather than the outcome of a steady-state analysis of individual performances.

Nevertheless, the Samberg and Salthouse study provides important information about age and attention, and the research illustrates the utility of an AOC analysis in this regard. As they pointed out in their paper, other research on divided attention has not controlled for variables that might indirectly interfere with the performances of older adults, such as sensory problems, inappropriate motivation, deficits in undivided attention, and the like. The AOC analysis is designed to control for these factors by evaluating the cost of divided attention relative to performances under undivided conditions. And when the AOC analysis was applied to data from older and younger adults, older adults were found to be as capable of distributing their attention between two stimulus sources as were younger ones, a finding that contradicts the conventional wisdom about age and attention.

The AOC applied to operant discriminations

The value of further analyses using the AOC approach is apparent. Additionally, it is important to examine age-attention relationships with a range of experimental paradigms so that the generality of effects can be established. These considerations led us to undertake research on divided attention using procedures similar to those followed in the study of human operant conditioning. These included explicit reinforcement for responding, reduced reliance on instructions as the technique for controlling divided attention, and a single-subject rather than a group-statistical research design.

The research (Hale and Baron, 1984) employed a conventional operant paradigm, matching-to-sample discriminations. In this type of discrimination, brief exposure to a sample stimulus is followed by a pair of choice stimuli, and only responses to the choice stimulus that match the sample are reinforced. As shown in Figure 8.5, division of attention was studied by using samples that were comprised of two-element compound stimuli (nonalphanumeric typewriter keyboard symbols, e.g. '%', and '$', positioned side by side). One of the sample elements was the positive member of the subsequent pair of discriminative stimuli; the negative member of the pair always was a symbol that was absent from the sample (e.g. '#'). Thus, accurate responses to the pair of choice stimuli required inspection of both elements of the compound sample. The stimuli used in each discrimination were drawn from a pool of eight items so that a given stimulus could be either positive or negative, depending on the trial.

Rather than employing pre-experimental instructions, division of attention was controlled on each trial by presenting information about the likelihoods that either of the elements would reappear. As illustrated in Figure 8.5, a compound stimulus ('$' and '%') might be preceded by the display, '90:10', which indicated that the left element of the sample ('$') would stand a 9 in 10 chance of reappearing as one of the choice stimuli, and the right element ('%') a 1 in 10 chance. Shown in the diagram are the four possible displays during the subsequent (delayed) choice phase of the discrimination. Delivery of the reinforcer (a signal of monetary payment) followed responses to the correct stimulus. Responses to the negative stimulus ('#') went unreinforced.
Within this procedure, the probability information was varied from trial to trial. The values at either extreme, '100:0' and '0:100', called for exclusive attention to either the left or right element of the sample. Intermediate conditions comprised the following values: 90:10, 70:30, 50:50, 30:70, and 10:90.

As is customary in operant research, the critical data were collected when performances were asymptotic and the subjects, older and younger men (65-75 yrs versus 19-25 yrs), were well acclimated to the procedures. An essential part of the analysis was that data were collected in the form of the speed with which the man selected one or the other of the choice stimuli. The tasks, although demanding, were designed to produce low error rates; these were no more than 3-4 per cent for men of either age. From the standpoint of age comparisons, this helped guarantee equivalent mastery of the information provided by the sample. Under conditions of high accuracy, response speed can serve as a highly sensitive behavioral index, one which has been used successfully to study such complex performances as memory and choice (Posner, 1978).

A general finding with regard to response speeds was that the older men were slower across the range of experimental conditions (this outcome is consistent with the well-known phenomenon of response slowing in older adults; see Cerella, Poon, and Williams, 1980). The speed data were subjected to AOC analyses, the results of which are shown for two young and two old subjects in Figure 8.6. It may be seen that in all four cases, the division of attention was accomplished only at some cost. Also apparent is that the tradeoffs are convex rather than linear. Such convex AOC functions indicate that the extent of the cost was moderate (cost indices ranged from 0.21 to 0.33). Finally, the analyses summarized in Figure 8.6 provide no basis for concluding that our procedures detected age differences in either the form of the AOC functions or the associated cost indices (we have not seen differences in these regards in work with other subjects). In other words, the older men were as capable of dividing attention as their younger counterparts.

The two studies discussed above, one conducted within a cognitive framework (Somberg and Salthouse, 1982) and the other within a behavioral one (Hale and Baron, 1984), demonstrate the utility of AOC analyses for the study of age differences. There was agreement about the absence of age differences in the cost of divided attention for individuals of different ages. A difference, however, concerns the nature of the tradeoff. Somberg and Salthouse's data, based on the accuracy of the choice response, suggested that the tradeoff is a linear one. But our work with a response speed measure indicated the tradeoff to be quite nonlinear (convex). It is not clear why the response measure should influence the shape of the AOC, and the fact that Sperling and Melchner's (1978) accuracy data also showed a nonlinear tradeoff implies the role of other factors. One possibility is simply that the task was more difficult for the subjects, both old and young, in Somberg and Salthouse's experiment.

Competition and concurrent schedules of reinforcement

We have discussed the concept of divided attention cost and the value of the AOC analysis as a mathematical description of attentional tradeoffs. The form assumed by the AOC characterizes the interaction between the particular tasks under study. Given this description, one then can investigate the variables that control the form of the tradeoff by analyzing the structure of the tasks and the nature of their incompatibility. But such analyses are necessarily incomplete.
because they do not address the variables controlling the way attention is distributed. This is because the AOC analysis is designed to specify the range of performances that are possible within the constraints of the situation. The analysis does not specify where on the AOC function the individual's performances will fall.

Questions about why an individual may pay more attention to one stimulus than another represent a concern with processes of motivation and reinforcement, rather than a concern with structural aspects of the tasks. Thus, identification of the variables that control the way attention is distributed requires a functional analysis. As Catania (1973) has pointed out, the degree of interest in functional rather than structural issues is a major difference between behavioral and cognitive approaches within psychology. Accordingly, we found it necessary to borrow the AOC approach from the cognitive tradition to describe the form of the tradeoff when there are competing sources of stimulus control (structure). We now turn to the behavioral tradition, more specifically to operant studies of choice behavior, to explore behavioral outcomes when responses to concurrent stimuli are differentially reinforced (function).

The Matching Law

For the operant psychologist, choice is the competition between different reinforcement schedules for the control of behavior. In a commonly studied laboratory procedure, a hungry pigeon can obtain food by pecking on two keys, each associated with a different schedule of reinforcement. Increased control over responding by one schedule must reduce the control exerted by the other. The essential aspects of this interaction are exemplified by Herrnstein's (1961) seminal experiment. In a two-key chamber, the pigeon's pecks on the left and right keys were reinforced according to different variable-interval schedules. Herrnstein discovered that a simple equation, now known as the Matching Law, described responding to pairs of schedules differing in their average rates of reinforcement. For each pair of schedules, the relative rate of pecking one of the keys (pecks on that key divided by total pecks) matched the relative rate of reinforcement (the number of reinforcers produced by pecks on that key divided by total reinforcers). This relation may be expressed mathematically as:

$$R_1/(R_1 + R_2) = r_1/(r_1 + r_2)$$

[8.3]

where $R_1$ is the number of responses on one key, $r_1$ the rate of reinforcement for pecks on that key, and $R_2$ and $r_2$ are responses and reinforcers associated with the second key. For example, if responses on the left key produced three-quarters of all obtained reinforcers, then this relative reinforcement proportion is matched by relative responding on the two keys such that three-quarters of the total responses are made on the left key.
conceptualized as investigations of divided attention as well as investigations of choice.

Consider in this regard a study reported by Baum (1975) in which concurrent operant schedules were incorporated into game-like procedures. The college-student subject was told that he was the captain of a spaceship under siege and that he could defend himself by ‘detecting and destroying two types of enemy missiles: red missiles and green missiles’. By depressing either of two keys, sensors for one or the other type of missile were activated, thus allowing detection of the missile if it was present. Through operation of a second key, the missile could be destroyed. Within this procedure, detection and destruction of missiles constituted the reinforcer, and the rate at which the missiles were presented, the reinforcement schedule.

Figure 8.8 shows results for two subjects; note that data are presented as allocation of time (rather than responses) to the alternatives. The figure shows that the relative amount of time that the sensor for red missiles was activated closely matched the relative number of red missiles that were detected (again, a straight line with a slope of 1.00 provides a good fit to the points). In other words, the subjects divided their viewing time in accord with the probability that reinforcement would be obtained.

There is further evidence from operant experiments that division of viewing time matches the probability of the event being viewed. For example, Schroeder and Holland (1969) measured the eye movements of subjects, who were monitoring two pairs of meters. The relative number of fixations on each pair matched the relative number of needle deflections detected by the subject. Conger and Killeen (1974) conducted an innovative test of the Matching Law within a social context. Their subjects participated in a group discussion in which the other members of the group (collaborators of the experimenter) systematically varied the extent to which they agreed with the subject’s statements. Results indicated that the amount of time the subject spent looking at a particular individual matched the relative number of statements of agreement.

Because the above studies were motivated by efforts to test the Matching Law with humans, their status as experiments on divided attention has largely gone unrecognized. But the formal similarities are apparent. In each case, the procedures required that subjects divide their attention between stimuli that competed for the control of behavior. Thus, subjects directed their attention (although this is not the language used by the authors of the reports) to possible green missiles or red missiles, to the left pair of meters or the right pair of meters, or to one or another member of the discussion group. In each case, the results indicated that increased control by one stimulus was associated with decreased control by the other. Moreover, the results further indicated that the relative amount of attention paid to each stimulus was determined by the relative rate of reinforcement associated with that stimulus.

There are, of course, a number of differences between these operant experiments and the conventional investigations of divided attention described in previous sections. One difference is the detailed study of the behavior of a
small number of subjects rather than brief observations of a larger number of subjects. Another is the response chosen for study. The operant studies relied on the time spent observing the stimuli, whereas the dependent measure in divided attention studies has been the accuracy or reports about the stimuli (Somberg and Salthouse, 1982, Exp. I; Sperling and Melchner, 1978), or less frequently, the speed of responding (Somberg and Salthouse, 1982, Exp. II; see also Hale and Baron, 1984). But the similarities appear to outweigh the differences, and the experiments raise some intriguing questions: Is the division of attention in all of these studies functionally equivalent? Is the competition between stimuli for control of behavior governed by the rates of reinforcement associated with the different stimuli? Do relative measures of control by different stimuli match the relative reinforcement rates associated with these stimuli, or are other relationships involved?

Answers to these questions are not simple because of the different conceptual frameworks in which the research was conducted. Nevertheless, there may be some promise in the strategy we have already adopted in the present effort—that of determining whether the data from experiments conducted in the different traditions will, if dealt with properly, present similar pictures. We presented the outcome of this strategy in a previous section where we took data from operant procedures (Hale and Baron, 1984) and subjected them to a type of analysis associated with cognitive experiments. The resulting AOC functions resembled those of a cognitive study of divided attention (Sperling and Melchner, 1978). In the following section, we describe outcomes when we reverse this strategy. We take the results of a cognitive study described above (Somberg and Salthouse, 1982) and reanalyze them using techniques associated with operant psychology. At issue is whether the data conform to the Matching Law.

Attention and matching

The main obstacle to the translation of results from cognitive experiments into operant terms is that the contingencies for responding usually are not made explicit. But a notable exception is the previously described Somberg and Salthouse (1982) experiment. It will be recalled that the payment for correct reports corresponded to the division indicated in the instructions (e.g., subjects told to divide their attention on a 70:30 basis received either 0.7 cents or 0.3 cents, respectively, for correct reports). This feature of the procedure provides a starting point for determining the effects of relative reinforcement on the competition between the stimuli for control.

Execution of the analysis is by no means straightforward. One problem pertains to the nature of the response. Somberg and Salthouse's procedure was arranged so that both stimuli (the inner and outer arrays) were well within the subject's central visual field, making simultaneous viewing possible. Consequently, the division of attention cannot be regarded as a simple tradeoff between two viewing responses that were directly measured (as was the case in the operant procedures; see Baum, 1975), and we were forced to infer the relative control of responding from the data on response accuracy.

A further difficulty is that response accuracy was the dependent measure. Assessment of relative stimulus control must in some way take into account the extent to which responses were correct by chance, that is, correct guesses not a result of stimulus control. We dealt with this problem by assuming that the proportion correct for each array, C, equaled the proportion actually detected, S, plus the proportion correct by chance. The probability of a correct guess was 0.5; therefore, C = S + 0.5 (1 - S) which rearranged yields S = 2 (C - 0.5). It follows that the relative control by one stimulus (in the present case defined as the relative attention to the inner array) is given by:

\[ \frac{S_1}{S_1 + S_2} = \frac{(C_1 - 0.5)}{[(C_1 - 0.5) + (C_2 - 0.5)]} \]

Despite the above complications, the reanalysis of the Somberg and Salthouse data yielded remarkably clear results. The outcome may be seen in Figure 8.9, which expresses 'relative attention' (more precisely, relative stimulus control) as a function of relative reinforcement. The figure shows that the division of attention closely matched the relative rate of obtained reinforcements. Also apparent is that age differences were virtually absent. In this connection, it will be recalled that the AOC analysis reported by Somberg and Salthouse led to the conclusion that the older adults were as capable of dividing their attention as the...
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young ones. Our reanalysis of their data in operant terms sheds additional light on this phenomenon; the older adults were as capable of dividing their attention in accord with the prevailing reinforcement contingencies as were the younger ones.

The similarity of the Somberg and Salthouse results to those of operant experiments suggests that similar processes may be involved in cognitive studies of divided attention and operant studies of matching. Furthermore, the relative rate of reinforcement appears to be an important and precise determinant of the allocation of stimulus control across a range of response measures, including relative accuracy, relative viewing time, and relative rate of responding.

In the above discussion, we mentioned a number of differences and similarities between attention experiments and operant choice experiments. At this point, it is important to emphasize the difference that, in our estimation, has had the largest bearing on the models that have emerged from each approach. As we explained earlier, the practice in most operant experiments is to select the competing responses in such a way as to make them completely incompatible. The pigeon, for example, can peck only one key at a time, and human subjects may be admonished not to press both buttons simultaneously (in Baum's study, simultaneous responses were not reinforced). An associated feature of the matching analysis is that outcomes are characterized as relative responding, expressed as proportions of ratios. As we explained earlier, the necessary result of these procedures is that tradeoffs are forced in the direction of linear relationships, i.e. relationships in which changes in one response are accompanied by equal but opposite changes in the other.

Now consider the usual procedure in experiments on divided attention. Here the experiment typically is arranged so that attention to the competing stimuli can occur simultaneously. Both stimuli are present within the visual field (or auditory field, e.g. dichotic listening) at the same time. Because the individual is exposed to both stimuli simultaneously, the nature of the tradeoffs in control is free to vary. Although tradeoffs may be linear under these circumstances (e.g. Somberg and Salthouse, 1982), they may assume nonlinear forms as well (e.g. Sperling and Melchner, 1978).

These considerations point to a limitation of operant research on choice that has been overlooked in discussions of research in this area. The methods used by operant psychologists have focused on linear tradeoffs to the exclusion of all other forms, because the linear form tends to emerge when competing responses are incompatible. Performances under such conditions are not unimportant, but the definition of choice is considerably broader, and a comprehensive analysis eventually will require consideration of compatible as well as incompatible responses. An analysis of tradeoffs between partially compatible operants modeled after the AOC and using an index of the cost of response incompatibility (mathematically equivalent to the divided attention cost index developed above) could prove quite useful in such an endeavor.

**Summary and conclusions**

The goal of this chapter was to examine some complex instances of stimulus control (divided attention) in human behavior. In the sections below, we outline the main conclusions of the effort: First, with regard to mathematical analyses of divided attention, as expressed by AOC and matching functions; second, with regard to the proposition that divided attention abilities decline with advancing age; and finally, with regard to the role of structure-function relations in the analysis of human conditioning.

**The relation of the AOC to the Matching Law**

The AOC and matching functions constitute mathematical descriptions of different aspects of divided attention, as this process has been investigated within cognitive and behavioral psychology. A common feature is that both approaches are directed toward the analysis of competition between psychological processes. Competition, however, is viewed from quite different vantage points. In the case of the AOC analysis, the focus is on the constraints surrounding the competition. The primary goal is to determine the cost of the competition. By comparison, the matching analysis is directed toward the outcomes of the competition. The goal is to specify the course of action expressed in the individual's behavior, given the constraints of the situation.

Descriptions exclusively in terms of one or the other approach necessarily are incomplete. Consider the limitations of the AOC analysis in this regard. To say that a subject's performance is described by a particular AOC function is to characterize the tradeoff when attention is divided in different ways. But the analysis leaves an essential question unanswered: Why was a specific data point (a specific combination of control by the two stimuli) obtained in a particular situation? Perhaps one might say, most simply, that the outcome reflected the way in which the subject chose to divide his attention. The trouble with this answer, from a behavioral standpoint at least, is that it raises, but leaves unanswered, the further question: Why did the subject choose this particular division of attention and not some other? It is with regard to questions of the latter sort that operant conceptions of choice and the associated Matching Law can be of use. Furthermore, it can be shown in mathematical terms that each of the two analyses represents an incomplete expression of the other.

Consideration of the exact mathematical relationship between the AOC and the Matching Law can be simplified by taking the intermediate step of expressing the law in terms of ratios rather than the proportions used previously (equation 8.3). The two expressions are, of course, mathematically equivalent. For example, if two-thirds of the total reinforcers are obtained for responding to one of two alternatives, the Matching Law predicts that two-thirds of total responding be allocated to that alternative, or, equivalently, that the
reinforcement ratio of 2:1 be matched by a 2:1 ratio of responding. In general terms:

\[ \frac{R_1}{R_2} = \frac{n_1}{n_2} \]  

[8.5]

where \( R_1/R_2 \) is the ratio of the alternative responses and \( n_1/n_2 \) is the ratio of the reinforcers for the responses.

For the present application of the Matching Law to the phenomenon of divided attention, the law also may be expressed as:

\[ \frac{S_1}{S_2} = \frac{r_1}{r_2} \]  

[8.6a]

where \( S_1/S_2 \) refers to the ratio of the control by the two stimuli. Finally, to allow representation of the Matching Law's predictions in AOC space (where performances under the control of one stimulus are plotted as a function of control by the second stimulus), the terms of equation 8.6a may be rearranged so that:

\[ S_1 = (r_1/r_2) S_2 \]  

[8.6b]

Equation 8.6b describes a straight line in AOC space that runs through the origin and which has a slope that is equal to the current reinforcement ratio \( (r_1/r_2) \). The relationship of the matching line to the AOC is illustrated in Figure 8.10. Three possible AOC functions are shown, one in which the cost index equals 0.67 (the concave function), one in which cost equals 0.50 (the linear function), and one in which cost equals 0.33 (the convex function). Also shown are the matching functions associated with three reinforcement ratios: 1:2, 1:1, and 2:1.

Consider data from a subject for whom there is a moderate cost of divided attention—a subject who trades off control by the first stimulus for control by the second stimulus according to a cost index of 0.33. According to the AOC analysis, this subject's performances can fall at any point along the convex AOC function, depending on how the individual 'chose' to divide attention between the two stimuli. But assume also that the reinforcement ratio was 2:1 for responses controlled by the two stimuli; that is, two reinforcers were received for attending to the first stimulus for every reinforcer received for the second. According to the Matching Law, this means that performances may fall anywhere along the line corresponding to that ratio of reinforcers (the line labeled 2:1). Thus, the subject's performance must satisfy two conditions: it must fall along a particular AOC function determined by the cost of divided attention and fall along a matching line determined by the reinforcement ratio. In our example, these two conditions are satisfied only at the point at which the 2:1 matching line interescts the AOC function associated with a cost of 0.33 (the solid circle in the figure).

While the preceding discussion has emphasized the incompleteness of the AOC as a description of divided attention, it is apparent that the same arguments can be directed against the Matching Law. For a subject confronted with a particular pair of tasks, the AOC function specifies a line that limits the range of possible performances. The Matching Law specifies, for a given reinforcement ratio, a line (the matching line in AOC space) that likewise limits the range of possible performances. But only the AOC function and the matching line taken together specify a single point that predicts what an organism will do in a given situation in response to a particular pair of reinforcement rates.

A last consideration pertains to behavioral transitions. In the previous example, the reinforcement contingencies were arranged so that more attention was paid to the first stimulus than to the second (ratio = 2:1). Now consider a change in the procedure: The contingencies are reversed so that the subject gains one reinforcer for attending to the first stimulus for every two reinforcers received for the second (ratio = 1:2). According to the Matching Law, performances should adjust so that increasing attention is paid to the second stimulus relative to the first. But as the division of attention is altered by the new contingencies, it must do so in the manner prescribed by the AOC, that is,
performances must move along the function until the division of attention matches the distribution of reinforcement. In the present case, this will be at the point at which the line labeled 1:2 in Figure 8.10 intersects the AOC function associated with a cost of 0.33 (the open circle at the point of the arrow). Thus, it may be seen that the AOC and the Matching Law, taken together, not only provide a theoretical basis for describing asymptotic (steady-state) performances, but also the transitions between steady states as responding adjusts to changes in the reinforcement contingencies.

As suggested earlier, analyses in terms of the AOC and the Matching Law represent concerns with structure and function, respectively. Catania (1973, 1984) discussed the important roles played by these concerns within psychology, tracing the distinction back to the writings of Titchener at the turn of the century. Catania made two important points that are well illustrated by the present effort. The first is that despite the antagonism that has existed between advocates of structural and functional analyses, the analyses themselves are complementary rather than mutually exclusive. Our analysis of divided attention shows that a comprehensive account must include the structural processes described by the AOC as well as the functional processes described by the Matching Law. The second point is that structural questions have been more the concern of cognitive than behavioral psychologists whereas the reverse is true with regard to functional issues. But this correlation appears to be more a matter of tradition than a necessary one, and the analysis presented here may encourage others to break with this tradition. As a behavioral psychologist, Catania advocated increased attention to structural questions, but his consideration of the issues was more programmatic than empirical. The present effort may be seen as an implementation of the inquiry that he proposed.

Age and divided attention

This brings us to the question of response competition as it pertains to the behavior of older adults. The phenomenon of divided attention has played a prominent role in the psychology of aging, in that deficits in divided attention are seen as a major contributor to deficiencies in a range of other performances (learning, memory, problem solving, etc.). But despite the widely held belief that older adults are deficient in their ability to divide attention, such a conclusion is not supported by the results reported by Somberg and Salthouse (1982) or the new data we presented here (Hale and Baron, 1984).

A critical difference from previous research was that performances were studied in terms of the AOC and the associated concept of divided attention cost. Equally important was that the procedures kept separate differences due to divided attention from differences that were not. We accomplished this by normalizing the data so that a subject's performance in the divided attention conditions was compared with performance in the undivided (100 per cent) condition. Somberg and Salthouse took the further step of adjusting the stimulus durations in a way that matched old and young subjects' performances under the undivided condition. The absence of age differences when these controls were included suggests that the age-related effects of previous experiments may have nothing to do with division of attention. Instead, the procedures may have picked up differences from other sources. Candidates here include differences in ability to perform under undivided conditions as well as differences in motivation, experience with the tasks, and, more generally, differences in the ways older and younger individuals react in laboratory situations.

Although previous reports about age-related deficits in divided attention may have been mistaken, one aspect of our analysis suggests an area of research that may reveal age differences. It is noteworthy that research on divided attention has been concerned primarily with how individuals respond to a given set of task conditions. Equally important is the question of how rapidly the division of attention can be altered in response to changing conditions. Thus, older individuals may have AOCs similar to younger ones, and ultimately they may adapt to changed reinforcement contingencies. Nevertheless, older adults may be slower in their ability to make adjustments in the way attention is divided when such changes occur. We know of no studies directly related to this question, however, and so its answer will have to await the results of future research.

Age and human conditioning

A final comment is in order about the relation of age to the study of human conditioning. As Catania (1973) pointed out, Titchener's effort to divide psychology into its fundamental components led him to describe not only a psychology of structure and a psychology of function, but a third psychology as well, that of 'psychogenesis'—a concern with 'the workings of the child's mind and the way in which it passes over into the adult mind'. Thus, the study of both structure and function must be placed within the context of the ways in which developmental variables influence behavioral outcomes. Considerable progress has been made since Titchener's time in the description of structural and functional aspects of the behavior of the developing child. By comparison, inquiry into structural and functional changes during the remainder of the life span remains a relatively untapped research area.

Behavioral changes in the adult often are seen as the continuation of a developmental process originating in childhood. In the case of the child, however, changes are characterized by a progression toward enhanced behavioral capabilities, and the acknowledged task of theories of child development is to account for increases in behavioral competence with age. The picture is different when one turns to the development of the older adult. Here the characteristic changes are those associated with declining capabilities—
The view taken here concerning the importance of a developmental approach is quite consistent with recent trends in the study of conditioning, in particular, the revival of interest in the comparative psychology of learning. There is increasing recognition that conditioning theories must come to grips with the structural constraints that phylogenetic differences place on the conditioning process. Similarly, the study of human conditioning must consider the possible constraints due to developmental differences. In this regard, it is important to note that the young adults who serve as subjects in the typical psychology experiment represent only one, somewhat arbitrarily selected, point along the developmental continuum. Systematic structural and functional analyses of the behavior of other age groups obviously are needed for a complete account. The present effort suggests an integrated approach which focuses on the interplay between structure and function. This approach should further understanding of the ways behavioral potentials and their realization change throughout the life span.

References

Haté, S., and Baron, A. (1984, May). Matching to compound samples: An operant paradigm to study divided attention in young and old adults. Paper presented at the meetings of the Association for Behavior Analysis, Nashville, TN.


