1 *Attention to Action*

Willed and Automatic Control of Behavior

DONALD A. NORMAN AND TIM SHALLICE

Much effort has been made to understand the role of attention in perception; much less effort has been placed on the role attention plays in the control of action. Our goal in this chapter is to account for the role of attention in action, both when performance is automatic and when it is under deliberate conscious control. We propose a theoretical framework structured around the notion of a set of active schemas, organized according to the particular action sequences of which they are a part, awaiting the appropriate set of conditions so that they can become selected to control action. The analysis is therefore centered around actions, primarily external actions, but the same principles apply to internal actions—actions that involve only the cognitive processing mechanisms. One major emphasis in the study of attentional processes is the distinction between *controlled* and *automatic* processing of perceptual inputs (e.g., Shiffrin & Schneider, 1977). Our work here can be seen as complementary to the distinction between controlled and automatic processes: we examine action rather than perception; we emphasize the situations in which deliberate, conscious control of activity is desired rather than those that are automatic.

In this chapter we will be particularly concerned with the different ways in which an action is experienced. To start, examine the term *automatic*: it has at least four different meanings. First, it refers to the way that certain tasks can be executed without awareness of their performance (as in walking along a short stretch of flat, safe ground). Sec-

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ond, it refers to the way an action may be initiated without deliberate attention or awareness (as in beginning to drink from a glass when in conversation). Third, it is used in cases such as the orienting response, in which attention is drawn *automatically* to something, with no deliberate control over the direction of attention. And finally, within contemporary cognitive psychology, the term *automatic* is often defined operationally to refer to situations in which a task is performed without interfering with other tasks. In this situation, *automatic* is principally defined to mean that the task is performed without the need for limited processing resources (Shiffrin & Schneider, 1977), although variations on this theme are prevalent (e.g., Kahneman & Treisman, 1983; Posner, 1978).

It is possible to be aware of performing an action without paying active, directed attention to it. The most general situation of this type is in the initiation of routine actions. Phenomenally, this corresponds to the state that Ach (1905) describes as occurring after practice in reaction time tasks. Over the first few trials, he said, the response is preceded by awareness that the action should be made, but later there is no such awareness unless preparation has been inadequate. In such well-learned tasks the subject does experience the response as proceeding with "an awareness of determination," even if it is not immediately preceded by any experience of intention to act. Awareness of determination can, however, be absent. One example comes from the study of slips of action (Norman, 1981; Reason, 1979; Reason & Mycielska, 1982): one may find oneself doing a totally unexpected set of actions, much to one's own dismay.

In contrast to acts undertaken without active, directed attention being paid to them are those carried out under deliberate conscious control. This distinction corresponds closely to Williams James's (1890) distinction between "ideo-motor" and "willed" acts. To James, "wherever movement follows unhesitatingly and immediately the notion of it in the mind, we have ideo-motor action. We are then aware of nothing between the conception and the execution." He contrasted these with acts which require will, where "an additional conscious element in the shape of a fiat, mandate, or expressed consent" is involved.

Experientially, a number of different sorts of tasks appear to require deliberate attentional resources. These tasks fit within the following categories:

1. They involve planning or decision making
2. They involve components of troubleshooting
3. They are ill-learned or contain novel sequences of actions
4. They are judged to be dangerous or technically difficult

5. They require the overcoming of a strong habitual response or resisting temptation.

The general principle involved is that these are special situations in which the uncontrolled application of an action schema is not desired for fear that it might lead to error.

I. Theory

Our goal is to account for several phenomena in the control of action, including the several varieties of action performance that can be classified as automatic, the fact that action sequences that normally are performed automatically can be carried out under deliberate conscious control when desired, and the way that such deliberate control can be used both to suppress unwanted actions and to enhance wanted ones. In addition, we take note both of the fact that accurate, precise timing is often required for skilled performance and the fact that it is commonly believed that conscious attention to this aspect of performance can disrupt the action. Finally, in normal life numerous activities often overlap one another, so that preventing conflicts between incompatible actions is required.

These phenomena pose strong constraints upon a theory of action. The theory must account for the ability of some action sequences to run themselves off automatically, without conscious control or attentional resources, yet to be modulated by deliberate conscious control when necessary. Accordingly, we suggest that two complementary processes operate in the selection and control of action. One is sufficient for relatively simple or well learned acts. The other allows for conscious, attentional control to modulate the performance. The basic mechanism, *contention scheduling*, which acts through activation and inhibition of supporting and conflicting schemas, is proposed as the mechanism for avoiding conflicts in performance. Precise timing is handled by means of "triggers" that allow suitably activated schemas to be initiated at the precise time required. The mechanisms for contention scheduling and triggers follow those developed by McClelland and Rumelhart (1981) and Rumelhart and Norman (1982).

Start by considering a simple, self-contained, well-learned action sequence, perhaps the act of typing a word upon the receipt of a signal. This action sequence can be represented by a set of schemas, which when triggered by the arrival of the appropriate perceptual event result in the selection of the proper body, arm, hand, and finger movements. Whenever the action sequence is effected, its representation by means

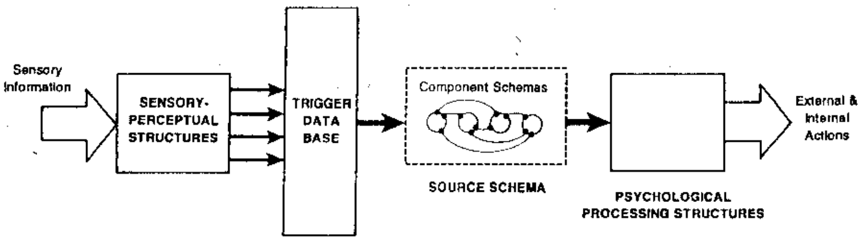

FIGURE 1. A horizontal thread. For well-learned, habitual tasks an autonomous, self-sufficient strand of processing structures and procedures can usually carry out the required activities without the need for conscious or attentional control. Selection of component schemas is determined, in part, by how well the "trigger conditions" of the schema match the contents of the "trigger data base." Such a sequence can often be characterized by a (relatively) linear flow of information among the various psychological processing structures and knowledge schemas involved: a horizontal thread.

of action schemas constitutes a "horizontal thread." The important point is that the processing structures which underlie a horizontal thread can in principle be well specified. The general nature of the processing structure for a simple action sequence is shown in Figure 1.

When numerous schemas are activated at the same time, some means must be provided for selection of a particular schema when it is required. At times, however, there will be conflicts among potentially relevant schemas, and so some sort of conflict resolution procedure must be provided. This is a common problem in any information-processing system in which at any one moment several potential candidates for operation might require access to the same resources or might result in incompatible actions. (McDermott & Forgy, 1978, discuss this issue for production systems and Bellman, 1979, discusses the problem with respect to animal behavior.)

The procedure we propose is constrained by the desire to transmit properties by means of the single variable of amount of activation, a concept consistent with current psychological theory. We propose that the individual schemas of the horizontal threads each have an activation value that is determined by a combination of factors, some that operate among schemas, some that result from special processes that operate upon the schemas.

A schema is selected once its activation level exceeds a threshold. Once selected, it continues to operate, unless actively switched off, until it has satisfied its goal or completed its operations, or until it is blocked when some resource or information is either lacking or is being utilized by some more highly activated schema. The activation value is important

primarily in the selection process and when the selected schema must compete either for shared resources or in providing component schemas with initial activation values.

The scheduling is, therefore, quite simple and direct. No direct attentional control of selection is required (or allowed). Deliberate attention exerts itself indirectly through its effect on activation values. All the action, therefore, takes place in the determination of the activation values of the schemas.

A. Contention Scheduling

To permit simultaneous action of cooperative acts and prevent simultaneous action of conflicting ones is a difficult job, for often the details of how the particular actions are performed determine whether they conflict with one another. We propose that the scheduling of actions takes place through what we call *contention scheduling*, which resolves competition for selection, preventing competitive use of common or related structures, and negotiating cooperative, shared use of common structures or operations when that is possible. There are two basic principles of the contention scheduling mechanism: first, the sets of potential source schemas compete with one another in the determination of their activation value; second, the selection takes place on the basis of activation value alone—a schema is selected whenever its activation exceeds the threshold that can be specific to the schema and could become lower with use of the schema.

The competition is effected through lateral activation and inhibition among activated schemas. What degree of lateral inhibition exists between schemas on the model remains an open issue. Schemas which require the use of any common processing structures will clearly need to inhibit each other. Yet the degree of inhibition cannot be determined simply *a priori*. Thus, some aspects of the standard refractory period phenomena can be plausibly attributed to such inhibition between schemas; explanations based upon conflicts in response selection fit the data well (Kahneman, 1973). Unfortunately, it is not always clear how to determine when two tasks use common processing structures. The experimental literature on refractory periods reveals interference between tasks involving the two hands. This suggests that responses involving the two hands may use common processing structures. However, one cannot assume that the two hands inevitably involve a common processing structure, as refractory period effects can disappear if highly compatible tasks are used (Greenwald & Shulman, 1973). On the model, as tasks become better learned, the schemas controlling them could become more specialized in their use of processing structures, reducing potential structural interference and minimizing the need for mutual inhibition among schemas.

B. Determination of Activation Values

We divide activational influences upon a schema into four types: influences from contention scheduling, from the satisfaction of trigger conditions, from the selection of other schemas, and from "vertical thread" influences. Trigger conditions specify under what conditions a schema should be initiated, thus allowing for precise environmental control of performance. How well existing conditions match the trigger specifications determines the amount of activation contributed by this factor.

Selection of one schema can lead to the activation of others. Any given action sequence that has been well learned is represented by an organized set of schemas, with one—the source schema—serving as the highest-order control. The term *source* is chosen to indicate that the other component schemas of an action sequence can be activated through the source. We assume that the initial activation values of component schemas are determined by means of their source schema. For example, when the source schema for a task such as driving an automobile has been selected, all its component schemas become activated, including schemas for such acts as steering, stopping, accelerating, slowing, overtaking, and turning. Each of these component schemas in turn acts as a source schema, activating its own component schemas (braking, changing gear, signalling, and so on).

C. The Supervisory Attentional System

The horizontal thread specifies the organization structure for the desired action sequence. However, a schema may not be available that can achieve control of the desired behavior, especially when the task is novel or complex. In these cases, some additional control structure is required. We propose that an additional system, the Supervisory Attentional System (SAS), provides one source of control upon the selection of schemas, but it operates entirely through the application of extra activation and inhibition to schemas in order to bias their selection by the contention-scheduling mechanisms. (A planning mechanism which performs an analogous function in problem-solving programs has been simulated by various researchers; see, for example, Boden, 1977). The

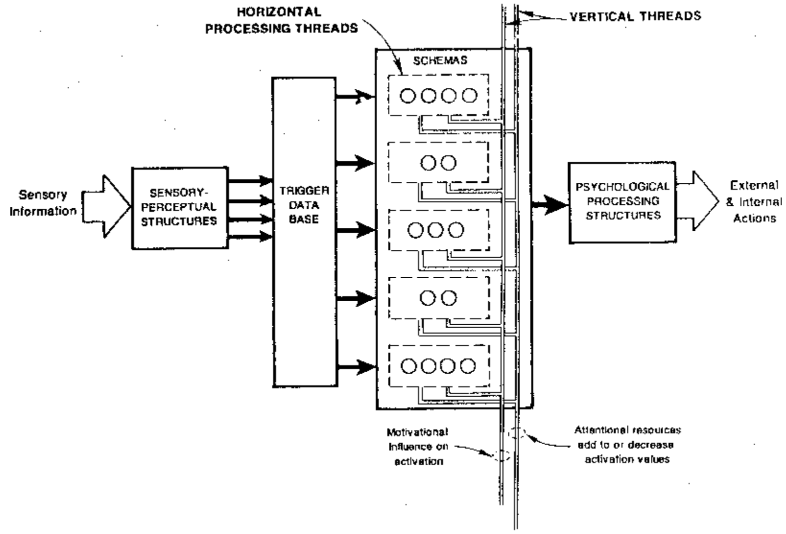

FIGURE 2. The overall system: Vertical and horizontal threads. When attention to particular tasks is required, vertical thread activation comes into play. Attention operates upon schemas only through manipulation of activation values, increasing the values for desired schemas, decreasing (inhibiting) the values for undesired ones. Motivational variables are assumed to play a similar role in the control of activation, but working over longer time periods. To emphasize that several tasks are usually active, with the individual components of each task either being simultaneous or overlapping in time, this figure shows five different horizontal threads. Some means of selecting the individual schemas at appropriate times while providing some form of conflict resolution becomes necessary. The interactions among the various horizontal threads needed for this purpose are indicated by the lines that interconnect schemas from different threads.

overall system is shown in Figure 2. Note that the operation of the SAS provides only an indirect means of control of action. *Attention*, which we will associate with outputs from SAS, controls only activation and inhibition values, not selection itself. Moreover, it is control overlaid on the horizontal thread organization. When attentional activation of a schema ceases, the activational value will decay back to the value that other types of activating input would produce.

In addition, we assume that motivational factors supplement the activational influences of the SAS. We take motivation to be a relatively slow-acting system, working primarily to bias the operation of the horizontal thread structures toward the long-term goals of the organism by activating source schemas (and through their selection component schemas).

II. EVIDENCE

That horizontal thread control of action may be viewed within a schema framework is too well known to need reviewing here (see, e.g., Pew, 1974, Schmidt, 1975). There are four major aspects of the model that require assessment:

1. Actions under deliberate conscious control involve a specific mechanism in addition to those used in automatic actions.
2. Attentional processes can modulate the selection process only by adding activation or inhibition. Attention to action is neither sufficient nor necessary to cause the selection of an action sequence.
3. Attentional processes are primarily relevant to the initiation of actions, not for their execution.
4. Selection between competing action sequences takes place through the mechanism of contention scheduling.

Now let us examine the evidence for these aspects of the model.

A. *Evidence for a Distinct Supervisory Attentional System: Neuropsychological Findings*

A major feature of our model is that for well-learned action sequences two levels of control are possible: deliberate conscious control and automatic contention scheduling of the horizontal threads. Possibly the strongest evidence for the existence of both levels comes from neuropsychology. The functions we assume for the supervisory attentional control—those that require "deliberate attention"—correspond closely with those ascribed by Luria (1966) to prefrontal regions of the brain, thought by Luria to be required for the programming, regulation, and verification of activity. In this view, if the Supervisory Attentional System were damaged the resulting behavior should be similar to that exhibited by patients with prefrontal lesions.

On the model, well-learned cognitive skills and cognitive procedures do not require the higher-level control system. Higher-level control becomes necessary only if error correction and planning have to be performed, if the situation is novel, or temptation must be overcome. It is well known in clinical neuropsychology that lesions confined to prefrontal structures leave the execution of basic skills such as the use of objects, speaking, and writing unaffected (see Walsh, 1978, for review). "Well able to work along old routine lines" is a classical characterization of such patients (Goldstein, quoted by Rylander, 1939). Quantitatively it has, for instance, been shown by McFie (1960) that performance of WAIS subtests is relatively unaffected by lesions to the frontal lobes. The model does predict impairments in the performance of tasks that require error correction or planning, or are in some basic way novel—just the constellation of deficits that are observed clinically in the so-called frontal syndrome (see Walsh, 1978).

Evidence for the contrast in performance in the two types of situations can be obtained from case studies of patients with frontal lobe lesions. A classic study was that carried out by Lhermitte, Derouesne, and Signoret (1972). Their two principal patients could perform certain Verbal and Performance WAIS subtests at normal level (Derouesne, personal communication). These were tasks which require the use of well-learned skills in routine fashion. Thus digit span, which uses maintenance rehearsal schemas, was well performed. When much novel programming of the external and internal action sequence was required, performance was extremely poor. Examples were WAIS Block Design or the reproduction of a complex figure—the Figure of Rey. However, performance could be greatly improved by providing a program for the patient; in the case of the Figure of Rey, this involved breaking down the total design into a series of hierarchically organized subcomponents.

Group studies of neurological patients also provide support. It is well established that patients with frontal lobe lesions have difficulties with error correction. The Wisconsin card-sorting test involves multidimensional stimuli and requires the patient to switch from sorting on one dimension to sorting according to another. In this task, frontal patients show a strong tendency to perseverate in sorting on the previously correct dimension, even when they are told they are wrong (Milner, 1964; Nelson, 1976). Planning, too, has been shown to present difficulties for these patients. The simplest example of such a defect is Gadzhiev's finding (see Luria, 1966) that frontal patients presented with a problem tend to miss out the initial assessment of the situation. Shallice and McCarthy (see Shallice, 1982) showed that patients with left frontal lesions are significantly more impaired than those with lesions in other sites in look-ahead puzzles related to the Tower-of-Hanoi; comparison of performance on this task with that on other tasks suggested that it was the planning component of the task that was affected. Novel learning tasks have also been shown to produce specific difficulties for frontal lobe patients. Petrides and Milner (see Milner, 1982) found that both patients with left frontal and those with right frontal lesions were significantly impaired in learning new arbitrary pairings presented one at a time in a random sequence.

Prediction about the effect of an impairment to the Supervisory

Attentional System can be approached in another way. On the model, the failure of this single mechanism can give rise to the apparent contradiction between increased perseveration and increased distractability, depending on the pattern of trigger–schema relations. What would be expected if behavior is left under the control of horizontal thread structures plus contention scheduling? If one schema is more strongly activated than the others, it will be difficult to prevent it from controlling behavior. By contrast, when several schemas have similar activation values, one should obtain another clinical characteristic of frontal patients: an instability of attention and heightened distractability (see Rylander, 1939; Walsh, 1978). Both types of results are also observed in animals with prefrontal lesions (see Fuster, 1980, for review).

If the properties of the Supervisory Attentional System seem to correspond fairly well with neuropsychological evidence, does the same apply to the properties of contention scheduling? One possible relation is with mechanisms in the corpus striatum of the basal ganglia, often thought to be involved in the selection of actions (see Denny-Brown & Yanagisawa, 1976; Marsden, 1982). The basal ganglia are innervated by one of the major dopamine projections, and dopamine release is in turn facilitated by amphetamine. Robbins and Sahakian (1983) have provided an explanation of the effects of increased doses of amphetamine based on the work of Lyon and Robbins (1975), in terms closely related to ours. The account goes like this: Increased amphetamine results in an increase in the speed with which response sequences are carried out and a decrease in the interval between them. At higher levels "competition for expression via the motor or executive system begins to occur between different sequences with the result that some sequences are aborted and their terminal elements are lost. Eventually, the performance of a complete sequence is drastically attenuated and the stereotype occurs." Robbins and Sahakian argue that increased dopamine release potentiates the activation level of schemas and leads to an increasing number of schemas being activated above threshold. In our terms, if the potentiation becomes too great, the lateral inhibitory control of contention scheduling is broken. Many schemas are selected at the same time, producing a jamming of almost all objects of behavior. Parkinsonism appears to provide a complementary condition.

B. *Attentional Processes Only Modulate Schema Selection*

The motivation for this aspect of the model is that attentional control is probably too slow and unwieldy to provide the high precision of

accuracy and timing needed to perform skilled acts. Deliberate conscious control is generally agreed to involve serial processing steps, each step taking on the order of 100 msec or more. Such control would simply be too slow to account for skilled human behavior that requires action sequences to be initiated just when environmental or internal conditions call for them; in some situations they must be accurate to the nearest 20 msec. This is consistent with the general view that deliberate control of skilled performance leads to deterioration of performance. Accordingly, in the model we allow attentional processes only to bias or modulate the operation and selection of schemas. Precise timing is controlled by the fit of stimulus input to that required by the set of trigger conditions for a schema.

Other factors are also involved. Thus, despite one's desire to attend to one set of signals, if the trigger conditions of another are sufficiently well met, the other may be selected in contention scheduling despite the attention directed toward the one: triggering activation can be more powerful than activation from the Supervisory Attentional Mechanisms. A classic example of this difficulty is the Stroop phenomenon. Another set of relevant findings comes from the classical literature on selective attention in which an attempt is made to keep the subject concentrating upon a primary task while other signals are presented. Certain classes of words presented upon a secondary channel can intrude upon or bias primary task performance, such as a word that fits within the context of the primary channel, or that has been conditioned to electric shock, or that has high emotional value. Performance of the other task is impaired when the interrupt occurs (e.g., Treisman, 1960, or in the refractory period paradigm, Helson & Steger, 1962). In terms of our model, these "intrusions" result from data-driven entry of action schemas into the contention-scheduling mechanism, and their selection there is due to the strongly activating properties of such triggers.

Further evidence that attention serves a biasing or modulating role comes from a study by McLean and Shulman (1978) that examined the role of attention on the speed of performance in a letter-matching task. Once a subject's attention had been directed toward a particular expectation, performance remained biased toward that expectation even after the subjects had been told that the expectation was no longer valid. The bias decayed slowly, lasting for around one second, thereby acting more like the decay of activation from a memory structure than of an attentional selection that could be quickly added or taken away. Although the emphasis in this experiment was on perception rather than action, their conclusion that attention acts by means of an activation level on memory units (schemas, in our vocabulary) is support for this aspect of the model.

Possibly the strongest evidence that conscious attentional control is not necessary for the initiation or execution of action sequences comes from the study of slips of action (Norman, 1981; Reason & Mycielska, 1982). In the class of errors known as "capture errors," the person appears to perform the action without either conscious control or knowledge. Capture errors are easily illustrated by an example: one of Reason's subjects described how, when passing through his back porch on the way to get his car out, he stopped to put on his Wellington boots and gardening jacket as if to work in the garden.

Consider what would happen on the model if a routine task is being carried out that does not require continuous monitoring and activation from the Supervisory Attentional System. Its component schemas can be selected using contention scheduling alone, so the Supervisory Attentional System could be directed toward activating some other noncompeting schema (i.e., "thinking about something else"), and the component schemas in the routine action would still be satisfactorily selected by contention scheduling alone. Occasionally, though, a schema that controls an incorrect action could become more strongly activated in contention scheduling than the correct schema and capture the effector systems. The supervisory system, being directed elsewhere, would not immediately monitor this, and a capture error would result.

Findings from the diary study of Reason (1983) provide support for an interpretation of this type of error in terms of the model. The data show that people typically rate themselves as being "preoccupied" and "distracted" in the situations wherein lapses occur. This would correspond in our model to the case in which no activation is being received for the "appropriate" schema from the supervisory system: instead, the supervisory system is activating a different, noncompeting schema. In Reason's data, both captured and capturing actions are rated as occurring "very often" and being "automatic." Moreover, the captured and capturing actions were rated as having very similar stimulus characteristics. These characteristics are all consistent with the model: frequently performed action sequences are apt to have developed sufficient horizontal thread structure that they could be carried out by contention scheduling alone—"automatically." The similarity of the captured and capturing actions is consistent with the suggestion that some data-driven activation of the capturing schema might take place and that trigger conditions appropriate for one sequence are likely to be appropriate for the other as well. All these factors maximize the chance of an incorrect schema's being more activated in contention scheduling than the correct one, thus leading to a capture error.

C. *Attentional Resources Are Primarily Relevant for Action Selection*

One theme of the model is that attentional resources are relevant only at the specific points in an action where schema selection is required. Thus, control of a hand movement in response to a signal will usually require attentional resources twice: once to initiate the schemas that start the motion, once to initiate the schemas that control termination of the motion (see Keele, 1973). This fits with the results of probe studies during movement where responses to probes at the start or end of the movement can be more delayed than those during execution (Posner & Keele, 1969). (The interpretation of probe studies is not straightforward—see McLeod, 1980—but U-shaped functions of the type obtained by Posner and Keele seem unlikely to arise artifactually.) When a simple movement is made to an external stop, the response time to a probe during the movement appears to be no greater than if no movement is being made (Posner & Keele, 1969; Ells, 1973). This suggests that when hand motion can be stopped by an external device the movement can be stopped without initiating an action sequence and without attentional control.

D. *Competition between Tasks*

On the model, the degree to which two tasks will interfere with each other depends upon a number of factors. These include structural factors critical for the contention scheduling mechanism, the balance of activation and inhibition in that mechanism, and the degree of learning which is relevant mainly for the degree of involvement required of the Supervisory Attentional System.

For most task combinations, precise prediction of the degree of interference depends on too many unknown parameters (see Shallice, McLeod, & Lewis, 1985). One obvious prediction is that "parallel" dual task performance should be most easily possible when one or both of the tasks can be performed without attentional control. This fits the experimental literature on monitoring (see Duncan, 1980, for review). When two response streams have to be initiated, the model makes the standard prediction that parallel performance is more likely if subjects are skilled and well practiced (see Allport, Antonis, & Reynolds, 1972; McLeod, 1977; Spelke, Hirst, & Neisser, 1976). Note that even in these situations performance normally deteriorates somewhat when two tasks are combined, even though there appear to be no obvious grounds for structural or attentional interference. We feel this indicates that even when the individual tasks are well learned at times there will be a need for schemas that require vertical thread activation for rapid selection. Thus, as Allport (1980) pointed out, in experiments involving piano playing conducted by Allport, Antonis, and Reynolds (1972), the one subject who showed no interference "was also the most competent of our pianists." The other subjects all found some technical challenge in the music such that "moments of emergency occurred" when recovery required some relatively unpracticed applications of keyboard technique and therefore, on our model, attentional resources.

E. *Will and Deliberate Conscious Control*

A major goal of our approach has been to produce an explanation for the different types of experience one can have of an action. Consider the types of information the Supervisory Attentional System would require in order to carry out its complex functions. Representations of the past and present states of the environment, of goals and intentions, and of the repertoire of higher-level schemas it could activate would all have to be available. Yet more would be necessary. The system would need to know aspects of the operation of a selected schema or, to be more precise, of those selected schemas which it could potentially activate (source schemas). It would need to know not only which source schemas had been selected but also the action sequences they produced and probably the eliciting triggers as well. Without such information, error correction would be a hopeless task, but it is a key function of the supervisory system.

How an action is experienced is dependent upon what information about it is accessed by the Supervisory Attentional System and upon whether the supervisory system activates source schemas itself and, if so, how strongly. This, therefore, allows a variety of states of awareness of actions to exist.

Consider the different meanings of *automatic* discussed earlier. The first two meanings which refer to automaticity in the initiation and carrying out of an action correspond to the selection and operation, respectively, of a schema without the supervisory system's assessing information relevant to it. In contrast are those occasions when a trigger not only activates a schema strongly and directly but also produces an interrupt in the supervisory system itself. This corresponds to the third, very different, meaning of *automatic*, wherein what is automatic is the attention-demanding characteristics of the stimulus. When the supervisory system does access some aspect of the triggering or selection of schema, or where it monitors the action sequence itself while at the same time providing no attentional activation to assist in schema selection, we have a correspondence for James' ideomotor acts. Schema selection is elicited solely by triggers, but information about the process is accessed at the higher level.

What happens when the supervisory system does produce attentional activation to modulate schema selection? We propose that *will* be this direction of action by deliberate conscious control. This definition is consistent both with the popular meaning of the term and with the discussions of will in the earlier psychological literature (e.g., James, 1890; Pillsbury, 1908). Thus, strongly resisting a habitual or tempting action or strongly forcing performance of an action that one is loathe to perform seem to be prototypical examples of the application of will. The former would appear to result from deliberate attentional inhibition of an action schema, the latter from deliberate activation.

In our view, will varies along a quantitative dimension corresponding to the amount of activation or inhibition required from the supervisory attentional mechanisms. The assumption that this activation value lies on a continuum explains why the distinction between willed and ideomotor actions seems quite clear in considering extreme actions but becomes blurred in considering those that require very little attentional effort. Thus, introspection fails in determining whether will is involved in the voluntary lifting of the arm. But there is no need to make a distinction if this act is simply identified as being near the zero point of the quantitative scale of attentional activation.

The idea that will corresponds to the output of the Supervisory Attentional System has certain other useful consequences. Consider the errors that occur with brief lapses of attention, when there is a failure to sustain will adequately. One type of error results following a decision not to do a step within a habitual sequence of actions. To eliminate the step requires deliberate (willful) inhibition of the relevant schema. If there is a momentary lapse of attention to the deliberate inhibition, the step may get done anyway. Closely related is the error that occurred to one of us, who decided not to take another bite of a delicious but extremely rich dessert; with only a brief lapse of attention, the cake got eaten.

Certain aspects of will require elaboration. In some circumstances an action may seem to require no will at all, yet at other times it will require extreme demands. Thus, getting out of bed in the morning is at times an automatic act and at other times requires great exertion of will. One explanation for this phenomenon is that activation of an action schema by the attentional mechanisms necessarily involves knowledge of consequences. When these are negative, they lead to inhibition of the source schemas which then must be overcome. In some cases, the self-inhibition can be so intense as to prevent or at least make very difficult the intended act. Thus, inflicting deliberate injury to oneself (as in pricking one's own finger in order to draw blood) is a difficult act for many people.

The elicitation of strong activation from the supervisory attentional mechanism is not necessarily unpleasant. Indeed, many sports and games seem to be attractive because they do necessitate such strong activation. In this case *concentration* is perhaps the more appropriate experiential equivalent rather than *will*. In addition, will is not just a matter of attention to actions. As Roy D'Andrade (personal communication) has pointed out, a willed act demands not only strong attentional activation; it also depends on the existence of a "mandated decision," independent of one's attending—a conscious knowledge that the particular end is to be attained. This mandate, in our view, would be required before the supervisory attentional mechanisms will produce their desired activation output. However, the critical point for the present argument is that the phenomenal distinction between willed and ideomotor acts flows from the separation of the supervisory attentional mechanisms from the systems they oversee. The phenomenology of attention can be understood through a theory of mechanism.

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2 The Motor Theory of Voluntary Thinking

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The theory proposed in this chapter—the motor theory of voluntary thinking (MTVT)—is not exactly new; its basic elements can be found in the motor theories of Bain (1888), Maudsley (1889), Ribot (1889), Pillsbury (1908), and Washburn (1916) to name just a few. Many of the ideas expressed below were commonplace at the beginning of this century, and the interested reader is encouraged to explore the original sources referenced within this chapter, which frequently contain detailed, anecdotal descriptions and lengthy logical arguments in support of these ideas. To maintain the clarity of my exposition, I will quote only a few examples from the early literature; it is not my intention to present a history of the theoretical formulations concerning the relation between the motor system and attention or thought (a brief history can be found in Smith, 1969). Rather, my purpose in writing the present chapter is to present some of these old ideas in the context of a cohesive theory that is as clear, plausible, and useful as possible.

It is my opinion that the current lack of popularity of motor theories derives from the fact that these theories often contained unnecessarily restrictive or implausible provisions and were often tied to physiological notions based on the limited knowledge of their times. However, I feel that to reject these theories in their entirety is to disregard a host of potentially useful ideas, which appeal to one's common sense and may stand in close agreement with one's own introspections. The MTVT, as expressed herein, is far from complete and should certainly be considered as work in progress. Nonetheless, I feel it is useful to present the theory at this time, especially considering the current increased interest in facial muscle action (Ekman, Friesen, & Ellsworth, 1972; Fridlund & Izard, 1984), in order to encourage the notion that overt or covert

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