LEARNING AND PRACTICING SKILLED PERFORMANCE

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INTRODUCTION

Skilled Performance

"Skilled Performance," as the term is used here, includes musical performance skills, all types of athletic skills, martial arts, dance, foreign language skills, playing games like chess or go, reading, drawing, etc. One of the goals of performance technology, as presented in this book, is to make high levels of achievement more accessible and more efficiently attainable. The technology suggests ways to sharpen traditional and present pedagogical practices in various performance disciplines, and in some cases proposes new methods and techniques of learning and practicing.

This book does not deal with the analysis of "talent," nor with the issues of genetic versus learned origins of high levels of expert achievement, motivational factors, or with correlations between high levels of expert achievement and other attributes. These topics are the subject of an extensive literature (e.g., Ericsson & Charness (1994)).

The technology of skilled performance learning presented here draws on the research literatures mainly from the disciplines that call themselves motor behavior, behavior analysis, cognitive psychology, and neuroscience. Each of these disciplines has generated knowledge that can fill gaps for the others. In fact, each of these disciplines contributes knowledge without which the present analysis of performance learning would not have been possible, thus providing a compelling example of how interdisciplinary efforts can lead to new and useful results. The book also draws on the pedagogical literatures of certain performance disciplines, on the practical experience of the author and others, and on engineering principles relating to the use of redundancy to achieve stability in any type of system.

Categories of Skilled Performance

We will classify skilled performances into three broad categories, and deal with each of these separately.

One category consists of repetitive performances where the goal is to execute the performance the same way every time, in conformity with some model or standard. Examples are the performance of musical compositions, dance routines, certain sports like bowling or high jumping, writing words long-hand, or reciting lines, as in acting.

A second broad category consists of interactive types of performance like playing tennis or chess, playing in an improvisational jazz band, or martial arts. These involve an ever-changing performance environment that most often includes the behavior of other individuals. Performances like doing arithmetic or solving a problem also involve variable performance conditions, but do not necessarily involve the behavior of others.

A third category, which includes reading, driving a vehicle, listening, simultaneous translation, taking dictation, or locomotion over uneven terrain, involves the additional characteristic of requiring the processing of a stream of information at a certain speed.

Presentation

This book describes a practical performance technology and some of its theoretical foundations. It addresses multiple audiences -- psychologists of all persuasions, neuropsychologists, physiologists, educators, performance teachers, coaches, trainers, and performers. Many of the examples are drawn from piano performance because that is a performance discipline with which I am familiar.[1] However, the performance technology presented is intended to be applicable to any type of skilled performance.

The type of support provided by the citations is indicated by means of a code of abbreviations to characterize the nature and relevance of each citation. These are the definitions of the abbreviation symbols used:

{Rev} A review of some literature relating to that point

{De} Describes or defines the term or the concept

{P} Makes a similar point

{E} An experimental study that supports the statement

Assertions made without citation should be viewed as my own conjecture.

> Indented sections printed in small type, like this sentence, present familiar examples of concepts being explained.

SOME PHYSIOLOGICAL BACKGROUND

Motor Programs

Before discussing performance technology proper, it may be helpful to review some research highlights from the fields of motor behavior and neuroscience.

Central to performance technology is the physiological concept of the motor program. As used prior to 1975 or so, the term "motor program" referred to neurally encoded information for executing specific movements —information as to <u>which</u> muscles will contract, the <u>force</u> with which they will contract, and the <u>order and temporal phasing</u> of the contractions ({P} Lashley, 1951; {De, Rev, P} Schmidt, 1982, p. 196-7). The motor program also ensures that the muscles involved, and the relevant portions of the nervous system, will be available and not otherwise engaged when needed for the movement being initiated ({P} Belen'kii, Gurfinkel, & Pal'tsev, 1967; {De, P} Kelso, 1982, p. 54-5; {P} Conrad, Benecke, & Goodman, 1983; {P} Mortimer, Eisenberg, & Palmer, 1987).

More recently, the concept of the motor program has been broadened to refer not only to the specific movement itself, but also to the result achieved by the movement, regardless of which particular effectors are involved ({Rev} Schmidt, 1988; {P} Von Hofsten, 1990; {Rev} Keele, Cohen, & Ivry, 1990; {Rev} Wiesendanger, 1990). This broadened concept is essentially the behavior analytic concept of the operant, defined as a unit of behavior that produces a particular effect on the environment ({De} Skinner, 1938). It is interesting to note in passing how two distinct lines of research, originating from widely divergent theoretical orientations, have converged on the same concept.

> When one tries to write with the non-preferred hand, the "result" program would specify what the written words should look like, regardless of what effector systems are used to achieve that result ({P} Wright, 1990). The results of writing one's name on a blackboard and writing it on a check look similar, and the general character of a handwriting is conserved, even though completely different muscle groups are involved ({E} Van Galen & Teulings, 1983; {E} Raibert, 1977).
>
> In musical performance, a type of effect could be what a performed piece of music sounds like ({P} Shaffer, 1981).

Some of the Experimental Evidence for Motor Programs

The oldest evidence that there are motor programs encoded in the central nervous system is provided by studies in which electrical brain stimulation elicits specific and highly organized and complex learned behavior, such as the utterance of sentences, the execution of coordinated movements, or the experiencing of hallucinatory perceptions ({E} Penfield & Roberts, 1959; {E} Penfield & Perot, 1963). Nottebohm {E} (1970) showed that when the innervation for part of a songbird's vocal apparatus is severed, the remaining part of the vocal apparatus, whose innervation is intact, will still perform its part of the song normally and with undistorted rhythm, in spite of the missing notes, thereby providing evidence that the motor program is still running, unaffected by the fact that half of the vocal effector apparatus is missing.

Different types of movements involve the participation of different CNS structures ({Rev} Keele, Cohen, & Ivry, 1990; {Rev} Schmidt, 1988; {Rev} Wiesendanger, 1990, pp. 62-68). Some motor programs are stored at the spinal level in their entirety: A decorticate cat in a harness will still run almost normally on a treadmill in response to the movement of the belt under its feet ({E} Shik and Orlovskii, 1976), and will adjust its gait almost normally when a paw hits a simulated obstacle ({E} Forssberg, Grillner, & Rossignol, 1975).

The Role of Feedback

Motor programs control both ballistic and feedback-controlled movements, including long and complex movements.

Some rapid movements, like seizing an object or striking it, do not depend on corrective feedback. Once initiated, they generally proceed without further adjustment, in "ballistic" rather than guided fashion ({Rev} Schmidt, 1988). Although short, fast movements are often ballistic, longer and slower movements are often affected by feedback ({E} Klapp, 1975; {E} Zelaznik, Hawkins, & Kisselburgh, 1983). Such movements may be ballistic early in their trajectory (within the first 200 milliseconds or so) and subject to adjustment by feedback in later portions of their trajectory, or alternately ballistic and guided, with provision for adjustment by feedback at certain points only ({E} Keele & Posner, 1968; {P} Schmidt, 1982, p. 195; {Rev} Meyer, Smith, Kornblum, Abrams, & Wright, 1990).

When a movement is repeated many times, it gradually loses its dependency on feedback and becomes increasingly ballistic ({E} Glencross, 1973; {P} Keele, 1982). However, even movements that have become ballistic as a result of repetition are still capable of being modified, disrupted, or stopped by feedback, but again usually only after the first 200 ms. or so ({P} Glencross, 1977; {P} Fairbanks, 1955). The feedback may direct the continuation of the movement, correct it, or bring it to a stop ({P} Adams, 1971; {P} Beaubaton, 1976; {P} Lee, 1978; {P} Fitch, Tuller, & Turvey, 1982), but the execution of the movement does not necessarily depend on any feedback ({E} Wilson, 1961; {E} Fentress, 1973; {E} Gentner, Grudin, & Conway, 1980).

CNS Activity Prior to Movement Initiation

Overt behavior is initiated within the CNS before there is any movement or muscle engagement. The process of movement initiation within the CNS has been mapped in terms of the brain structures involved ({Rev, P}, Paillard, 1982; {E} Georgopoulos, 1990). Different specialized neurons and CNS structures participate in each of the initiation process's separate aspects ({Rev} Wiesendanger, 1990, pp. 69-71). In studies that used direct recordings from motor neurons, Georgopoulos and Massey {E} (1987) showed that recordings taken directly from monkey neurons just prior to movement, predict the precise direction in which the monkey will point. There are specialized neurons dedicated to movement preparation rather than to movement per se. These are active just before a particular movement is to be executed ({E} Tanji and Kurata, 1983; {E} Evarts and Tanji, 1974; {E} Lecas, Requin, Anger, &

Vitton, 1986). The length of the pre-motor activity depends on the complexity (a) of the stimulus being responded to ({E} Klapp, Anderson, & Berrian, 1973), (b) of the decision being made ({E} Sternberg, Monsell, Knoll, & Wright, 1978), and (c) of the type of movement that is about to be executed ({Rev} Keele, Cohen, & Ivry, 1990).

In rapid sequences of movements, the CNS initiation phase for each movement may begin while the preceding movement is still in progress ({Rev, E} Semjen & Gottsdanker, 1990). An integral part of the initiation phase of certain complex movements is the advance preparation of the appropriate CNS sensory mechanisms to receive and process the anticipated feedback (the "corollary discharge") ({Rev} Schmidt, 1988, pp. 177-181; {P} Von Hofsten, 1990).

Complex movements that need to be executed smoothly are normally preceded by pauses. The covert activity that occurs during those pauses (e.g., during the time we say "uhhh" when speaking) appears to include (a) the accessing of programs that are about to be executed ({E} Spijkers & Sanders, 1984; {E} Kristeva, 1984; {E} Van Galen & Teulings, 1983); and (b) checking out the previously experienced (memory-stored) consequences that the about-to-be-executed movements have produced in the past (called "feedforward" ({E} Schmidt, 1988). Reaction-time data show a relationship between the complexity of a movement or decision and the length of the pre-movement pause. ({E} Henry & Rogers, 1960; {E} Klapp & Erwin, 1976; {E} Sternberg, Monsell, Knoll, & Wright, 1978; {E} Rosenbaum, 1980).

It should be stressed that the CNS events that precede a given movement, or access the program for it, must not be regarded as "causes" of that movement. Rather, the antecedent and concurrent neural events and the movement, taken together, comprise what behavior analysts call an operant.

PROGRAMS, ROUTINES, AND PERFORMANCE LEARNING

Motor Programs and Motor Routines

For the sake of clarity, we will use the term "motor routine" to refer to the actual behavioral events that occur when the motor program runs. Thus, the running of a motor program is the motor routine.[2]

A central concept of performance technology is that the execution of a new routine results in the creation of a new program. The act of executing the routine writes the program. When that new motor program then runs, the resulting routine is similar to the one that created the program ({P} Adams, 1971; {P} Guthrie, 1959).

But there appears to be a paradox here: How can a new routine be executed if the program for it does not yet exist? Answer: By running and stringing together smaller existing programs in new combinations and sequences. At the start, any performance learner can already execute fragments or sub-routines of the desired new performance. These sub-routines can serve as building block components from which the final desired performance can be assembled and synthesized. During learning, existing fragments and sub-routines are executed in combinations that approximate the new routine to be learned.

The Use of Pauses in Creating New Programs

Existing fragments of performance components are executed sequentially or concurrently. When they are sequential, the new performance is built by executing the building block sub-routines in the desired order, with pauses between them as needed. The pauses provide time for planning, assembling, and covertly rehearsing each sub-routine before executing it. They provide time needed for the covert CNS activity with which every motor routine begins ({P} Tanji and Kurata, 1983; {P} Lecas, Requin, Anger, & Vuitton, 1986; (Rev} Wiesendanger, 1990; {Rev} Keele, Cohen, & Ivry, 1990). As learning progresses, the pauses can be made progressively shorter, and the sub-routines eventually fuse to form the desired new routines. The results of this progression are sometimes called fluency or automatization.

> For pianists, the building block sub-routines may be groups of notes, scales, arpeggios, and chords. In language learning, they include routines for producing certain types of sounds, which are practiced separately before they are used in words or sentences. A fluent speaker makes few pauses.

Assembly of Concurrent Routines

Sometimes, building block sub-routines must be assembled to run concurrently, as when the performance involves different body parts executing routines simultaneously. The efficient procedure is to learn and practice the routines separately before assembling and synchronizing them.

> In playing most musical instruments, the two hands perform routines that are different but synchronized. A pianist plays a passage with both hands together after having learned the part of each hand separately.

> Dance routines often involve synchronized movements of the feet, body, arms, head, and eyes. These movements are often learned and practiced separately.

PARAMETERS OF MOTOR PROGRAMS

The Force Parameter

Each time a motor program runs, certain parameter settings determine the resulting routine's particular form and characteristics. Those parameters modify the execution of motor routines in ways that adapt the routine to varying circumstances.

An important parameter is the force with which the involved muscles will contract ({P} Ivry, 1986; {P} Schmidt, 1982 p, 196-7, 223-4). In general, the greater the force of the muscular contraction in a motor routine, the faster the resulting movement.

> In piano playing, the force applied to key depression determines how fast the key moves down, and consequently how fast the hammer is propelled against the strings, thereby determining loudness.
>
> In running, the more forceful the muscle contractions of the forward-propelling steps, the larger the steps and therefore the faster one runs ({E} Shik and Orlovskii, 1976).
>
> In dance, the greater the force of the muscle contractions that propel the body into a leap, the larger the leap (though force changes can produce other effects as well).
>
> In vocalizing, the force with which the diaphragm muscles push air through the larynx determines the speed and volume of the air flow and the loudness of the vocalization.

The setting of the force parameter can vary from one execution of a routine to the next, and can continue to vary throughout any single instance of the movement sequence comprising the routine.

The Force Parameter and Covert Routines

The force with which a muscle contracts depends on the number of muscle fibers that are enlisted in the contraction. The contraction of each individual muscle fiber is all-or-none. As the force of muscle contraction called for by the motor program (number of fibers enlisted and hence degree of muscle engagement) is reduced, the amount of movement is reduced. Visible movement occurs only if the force exceeds a certain level. If the force is below that level, no movement is visible and the routine is said to be "covert."

But even when the number of enlisted fibers is reduced to the point where there is no longer any visible movement at all, the force of the muscle contraction can often still be measured and recorded from the muscle as an electrical potential ({E} Hefferline & Keenan, 1963). The potential reflects the number of fibers enlisted ({E} Shaw, 1940; {E} Ewert, 1933). As far back as 1932, Jacobson showed that one could electrically record muscle potentials as correlates of "thinking" ({E} Jacobson, 1932); Max showed that deaf-mutes who use signing language sometimes exhibit electrical potentials in their finger muscles without visible movement when they think or dream ({E} Max, 1937). Skinner wrote that "internal speech" is an example of what we call thinking ({P} Skinner, 1953), and earlier, the behaviorist John B. Watson said that thinking was "sub-vocal talking." Still earlier, Plato said that many instances of thinking were "inner speech." Of course, not all covert or internal routines involve speech.

The psychological term "overt" refers to visible movement. The term "covert" has been applied to motor routines that are <u>not</u> visible. We could therefore say that the force parameter is also an "overtness" parameter. As will be seen, this "force/overtness" parameter is central to our understanding and analysis of performance learning. We know how to cause overt routines to become covert, and covert ones to become overt.

> When a child learns to read or do arithmetic silently, vocalization becomes increasingly covert, until the vocal apparatus is no longer engaged at all. Silent reading or mental arithmetic are examples of skills that are initially learned overtly, gradually become completely covert, and can be made overt again at will.

Motor Programs Can Run Without Muscle Engagement

The setting of the force/overtness parameter can be below the level where there is movement. We can reasonably infer that if the setting of the force parameter can shift in the direction of zero, it can also reach zero.
When it reaches zero, where no muscle fibers at all are enlisted, the program runs without engaging the muscles and without producing any change of muscle potential. This is reminiscent of running a car engine without the clutch engaging the transmission. But unlike clutch engagement, the engagement of muscles when a motor program runs is a matter of degree rather than all-or-none, with gradations of muscle engagement corresponding to the number of muscle fibers enlisted.

It is interesting to note, in passing, that many behaviorists (e.g. {P} Keller & Schoenfeld, 1950, pp. 212-217; {P} Kantor, 1924) advanced the notion that all forms of covert activity (including all "mental" activity or "thinking") always engage the muscles, though at such low levels that no visible movement occurs. But there is no evidence to support the notion that the myriad lightning events called "thinking" continuously engage and disengage the body's muscles. Such activity, serving no functional purpose, would be biologically maladaptive. Donald Cook has suggested that this old notion may have been motivated in part by the desire to plot a "scientific" escape from a philosophically uncomfortable mind-body dualism. An alternative notion, which is more theoretically parsimonious and convincing, is that motor programs may still run with the force parameter at zero and the muscles not engaged at all. Additional plausibility for this notion is based on considerations of evolutionary survival advantages.

> For example, covert speech is about 50% faster than overt speech, even after practice ({E} MacKay, 1982), and silent reading, though it may admittedly not consist of exactly the same routines as reading aloud, is substantially faster. Word articulation is often short-circuited, and some words are not "read" at all.

In general, routines can run faster covertly than overtly. The slowdowns entailed by continuous muscle engagement and disengagement, even when these are below the movement threshold, would be intolerably burdensome and wasteful.

The ability to execute routines covertly and fast, without any muscle engagement, and the elimination of the other physical and practical obstacles (such as gravity, friction, and inertia) that overt behavior inevitably encounters, conferred obvious survival advantages during evolution. We may have had ancestors unable to set the force parameter to zero, and our ability to reduce it all the way to zero (and thus to uncouple the muscles and engage in pure "thinking") would then have been achieved somewhere along the evolutionary line.

Overt and Covert Routines

We are now faced with a terminological problem, because the term "motor" refers to movement. How can a routine be "motor" if does not involve any movement or even muscle engagement? We will call the running of motor programs without muscle engagement "covert routines" and simply omit the term motor. Thus, a covert routine may engage muscles at sub-threshold levels or not at all.

We could also use the terms "behavior program" and "behavior routine, but the term "behavior" would be redundant, as everything we deal with in the present context is behavior. Even routines that are totally neural and involve no muscle engagement at all should be viewed as behavior, as it would be inconsistent and arbitrary to apply the term "behavior" only to visible and overt muscle movement. Such a narrow definition would require us to draw a line at an arbitrary point for number of muscle fibers that are enlisted by the routine. We will therefore apply the term "behavior routine," or "routine" for short, not only to overt routines, but also to routines that consist of neural activity only, and that are completely covert without any muscle engagement at all.

In addition to justifying this definition on grounds of elegance, there is also scientific support for viewing purely neural routines as behavior. The totality of the behavior analytic literature makes it plausible that completely covert routines share important properties with overt behavior ({P} Keller & Schoenfeld, 1950, 217-219; {P} Skinner, 1953; {E} Hefferline & Keenan, 1963; {P} Homme, 1965). For example, there is ample evidence that the same principles of learning apply to both. Therefore, the substantial body of knowledge termed "behavior analysis" should be applicable, or is at least relevant, to an analysis of performance learning, and to the development of a technology of learning performance skills.

Covert Routines in Overt Performance

Every performance consists of a weave of overt and covert routines. For example, a performer will often fleetingly "imagine" a motor routine just before executing it. This is probably a covert and sped-up version of a potentially-overt motor routine. We will call such routines "imagings" (a term that has previously been used in the psychology literature, e.g., ({De} Glenn, 1977). We will extend this term to encompass any combination of covert movement, visual imagery, and internal hearing.

The covert routines woven into an overt performance may be entirely non-verbal, as in imagings, or may include covert verbalizations like "Slow, slow, quick, quick, slow" as in prompting a dance step. Movements too can be imaged. A kinesthetic imaging of a motor routine may engage the muscles weakly or not at all. At least one reason why a motor routine can be executed much faster covertly than overtly is that the covert version is not subject to the physical limitations and impediments of overt movement.

Covert routines during an overt performance can perform several functions. One is to provide a "dry run" or "checkout" of a routine split seconds before it is executed overtly, in the "feedforward" sense discussed earlier (See the earlier section entitled "CNS Activity Prior to Movement Inititation"). Such a checkout would include making sure that all of the needed programs and sub-programs will be instantly available as needed so that the execution of the routine will not be interrupted or disrupted by delays in retrieving component sub-programs. The checkout would also ensure that all needed circuits are clear and all needed effectors available. Another function of the covert dry run is to review the environmental effects and consequences that were experienced when the same routine was executed on previous occasions. Such a dry run can make sure that these effects and consequences are the desired ones, and do not include undesired ones.

The Importance of Identifying and Teaching Covert Routines

For many types of performance, the covert components are the vital ones that should receive most or all of the teacher's or coach's attention. An extreme case is the behavior of playing games like chess or go, where all of the essential behavior is covert. The overt component, namely the act of moving the pieces, is trivial in that it does not need to be learned by most adults.

> In teaching chess skill, where all of the essential behavior is covert (picking up and moving the pieces is not essential to chess skill), a good chess teacher or coach asks the learner to "think out loud" ({P} Silman, 1991). As the learner then verbalizes overtly while pondering each move, the coach is provided with access to some of the learner's analytic behavior and can proceed to shape it. That analytic behavior later becomes completely covert and faster.[3] Also, the very act of verbalizing the thought process, and of thinking out loud, changes the behavior, even without the contributions of a coach ({P} Hayes & Hayes, 1989).

But even in performances that have an important motor component, like playing a musical instrument, dance, or sports, the covert routines (which involve no movement) are still often the vital ones. The teacher or coach must identify these and teach them in overt form. Performance teachers often call this "teaching the student how to think." Once overt, these routines become more accessible for shaping. With repetition, they will eventually become covert, faster, and less effortful ({P} Keller & Schoenfeld, 1950, pp. 204-5, 217-8).

There are also many types of performance that consist of a cascade of covert programs that run sequentially or in parallel, culminating in an overt motor routine, as in a "mental" multiplication, which occurs covertly and ends with an overt statement of the answer. The teacher's task is to identify and teach the covert part of the such performance skills.

In general, the covert routines are often the most important components of the performance. But they are also usually the most elusive, because, being invisible, they are difficult for the teacher or coach to observe. As a result, they are often overlooked and their importance unappreciated.

The Speed Parameter

Another program parameter is the speed with which the program will be executed ({P} Shapiro, 1977; {P} Stelmach, Mullins, & Tuelings, 1984; {P} Nihei, 1984; {Rev, P} Keele, Cohen, & Ivry, 1990). The speed parameter specifies the length of the time intervals between consecutive movements (such as depressions of piano keys, dance steps, or words in a sentence) that occur in a particular sequence ({P} Shapiro, 1977; {P} Stelmach et al., 1983; {P} Nihei, 1986; {P} Quinn & Sherwood, 1983; {Rev} Keele, Cohen, & Ivry, 1990) without changing the ratios among those time intervals (i.e. the rhythm). The ratios determine rhythm, and the absolute lengths of the time intervals determine the overall speed. Motor programs appear to encode rhythm by specifying the phasing of the muscular contractions.

There is experimental evidence that a change of speed, within limits, has a minimal effect on phasing or rhythm. A motor routine's rhythm is preserved, without special additional practice, when the routine is executed at a somewhat faster or slower tempo than the tempo at which it was originally learned ({E} Summers, 1975; {E} Carter & Shapiro, 1984; {E} Summers, Sargent, & Hawkins, 1984; {P} Grillner, 1981).

> This finding is confirmed by the experience of musical performers ({P} Michon, 1974). When pianists learn to play a certain piano passage at a certain speed, they are then able, without much difficulty, to play the same passage at a somewhat different speed (within limits) while preserving the rhythm. Similarly, if a spoken phrase is learned in a foreign language, that phrase can then be uttered somewhat faster or more slowly (again, within limits), with its other characteristics preserved.

Timing functions, and determination of the speed with which any given motor routine is executed, appear to be performed by the lateral cerebellum ({E} Ivry and Keele, 1989; {E} Ivry, Keele, & Diener, 1988) and perhaps also by the supplementary motor cortex ({E, P} Deecke, Kornhuber, Lang, Land & Schreiber, 1985; {Rev} Keele, Cohen, & Ivry, 1990).

Speed Changes and Phasing of Routines

As was noted above, the speed parameter maintains rhythmic constancy only within limited ranges of speed increments. The reason why rhythmic constancy breaks down beyond those ranges has to do with phasing of the component routines. A performance requires that the component routines terminate in the right sequence, because the desired effects occur at their termination points, not at their starting points.

> In typing, the key strokes must terminate in a certain sequence for the letters to be properly sequenced. In piano playing, the keys must be depressed in a carefully phased sequence for the rhythms, and note sequences, so as to produce the desired music.

But since each of the individual component routines (e.g., each keystroke), including its covert initiation phase, takes time from beginning to end, each individual routine must be initiated before the previous one is completed, if the termination points are to occur in rapid succession. So, the routines will overlap temporally, like a fallen row of dominos. If the routines' end points are compressed in time without the lengths of the individual component routines being compressed correspondingly, the routines must overlap. The more the speed is increased, the more the routines will overlap, to the point where there can be two or more routines in progress "in the pipeline" at the same time.

Practicing With Gradual Speed Changes

The phasing issue would not present a problem for speed changes if all of the component routines were of the same length, as the sequence of starting points would then remain the same as the sequence of termination points, regardless of speed. But the component routines are usually of different lengths.

> The analogy that comes to mind is the cook who starts each dish according to the required cooking time, and in a different order than the required completion times. In juggling pins, the second and sometimes the third and fourth pins are thrown up before the first one has been caught. And when we try to say something much faster than we normally say it, we may get "tongue twisted", because the component routines must then be initiated in a new and as-yet-unprogrammed sequence, if they are to terminate in the desired order. If the speed is increased too quickly, there is often a "tripping over oneself" effect.

Thus, a speed change will change the sequence and rhythm of termination points if the motor program specifies a given sequence and rhythm of starting points ({E} Gentner, Grudin, & Conway, 1980). The motor program generally determines the initiation points (the firing of the first neuron). Reversals of starting times are normally required when speed is changed significantly, if the sequence and rhythm of termination points is to be preserved, with new reversals being required at each new speed. What a speed increase must compress is the speed and rhythm with which the component routines terminate. That is why a performer who has learned a performance at a given speed can execute the performance only slightly faster or slightly more slowly. The motor program, which specifies the starting times, must therefore be changed and relearned at each new speed.

> Pianists know that in order to avoid mistakes while practicing, they must increase the speed at which they practice a passage very gradually ({P} Slenczynska, 1961, pp. 30-31).

Effort Flow as a Motor Program Parameter

The faster the overall performance, the greater the number of movements per unit time. If the force or effort of each movement remains unchanged as speed is increased, the effort flow (effort per unit time) is increased. The other way to increase effort flow is to keep the speed the same, but to increase the force with which each movement is made.

> In piano playing, a given level of loudness requires a given level of effort for each key depression. A faster performance speed at a given level of loudness then requires a higher overall level of effort flow than a slower speed. An increase in effort flow can be converted either into faster individual key depression with a resulting louder performance, or into faster playing. When practicing a passage slowly, pianists tend to increase the force of each key depression, presumably so as to approximate more closely the level of effort flow in the final performance. ({P} Gat, 1954).
>
> The same principle is seen operating in other types of performance. In dance, for example, the size of steps can be roughly inter-convertible with the speed at which the routine is executed.

So, when the speed parameter is set for a faster performance at a given level of loudness, the effort flow parameter must be adjusted accordingly. The automobile analogy that comes to mind is that when the engine speed is to be increased, it is necessary to increase the rate at which fuel is injected into the motor. Perhaps effort flow is proportional to speed times loudness.

Moment-To-Moment Parameter Changes

The settings of parameters like force, speed, or effort, and their changes, may be thought of as a series of options, modulations, or annotations of motor programs. Such annotations may be fluidly changeable during the routine. In more interactive performances, like martial arts or playing tennis, the moment-to-moment changes in the parameter settings would depend on feedback from visual and kinesthetic cues.

> A pianist, when playing a passage, continuously readjusts both the force and speed parameter settings from moment-to-moment. To produce a louder sound, the pianist applies greater force, with consequent faster key depressions, either to produce accents, or throughout longer passages. Similarly, the pianist may change the speed from phrase to phrase, or gradually, as in accelerations and decelerations.

PERFORMANCE SHAPING

Automatization of Routines

The term "chain" has been used by behavioral psychologists to refer to performances in which each routine provides the cue[4] for the next one ({P} Keller & Schoenfeld, 1950, pp. 197-230; {De} Skinner, 1938; {P} Mechner, 1963; {P} Millenson, 1967; {P} Verhave, 1966, pp. 36-38; {P} Brenner, 1986). After a chain has been repeated many times, the programs for the chain's routines become fused into a single longer program, with decreasing utilization of cues and feedback ({P} Glencross, 1973; {P} Keele, 1982). As this fusing process proceeds, the routine's properties become less and less chain-like. Thus, the chaining account provides an adequate description of only a certain transient stage in the learning of new programs —the stage reached when the initial assembly and shaping process has progressed to the point where cues trigger the successive routines, and before fusing and compression has set in.

The terms "automatization," "unitization," and "chunking" have been applied to the process that occurs as routines are repeated many times, and to the changes they undergo as a result ({P} Shiffrin, 1988, 740-767; {P} Schmidt, 1988 p. 74). These changes include: Acceleration, increased stereotypy, decreased disruptability, decreased modifiability by all types of interventions, decreased susceptibility to, or utilization of, feedback, shorter pre-initiation latencies ({P} Mechner, Hyten, Field, & Madden, 1992), increased ability to engage in other behavior at the same time, a decreased requirement for "attention" by the performer, and a decrease in the amount of CNS activity associated with the execution of the routine ({E} Schneider, 1985).

Automatization (also sometimes called fluency, when the result is valued) is the basic change that is sought in the learning and practicing of a skilled performance. However, as will be seen, the value of repetition depends on <u>what</u> is repeated and <u>how</u> it is repeated ({E} Trowbridge & Cason, 1932; {E} Baltes & Kliegl, 1992; {E} Kliegl, Smith, & Bates, 1989; 1990; {Rev} Ericsson, Krampe, & Tesch-Romer, 1993).

Reinforcement of Parameter Shifts in Performance Learning

In performance learning, reinforcement may work by perpetuating not the most recent <u>behavior</u>, but rather its most recent <u>direction of change</u>. What is repeated is the direction in which the settings of the routine's program parameters shift. The direction would be the one in which each parameter had shifted most recently ({P} Mechner, 1992, Chapter 9).

Reinforcement may not affect all parameters equally. For example, it may preferentially perpetuate increases in the force/overtness parameter, and may have a greater effect on overt routines than on covert ones.

> This parameter shift mechanism of reinforcement would explain the speed with which good animal trainers can shape complex behavior ({E} Pierrel & Sherman, 1963) (ref to Baileys' work). The trainer reinforces desirable direction shifts rather than desirable variants. A skilled trainer also avoids presenting reinforcements at moments when one of the routine's parameters shifted in an undesirable direction. The challenge to the trainer's skill is that each instance of a routine reflects several parameter shifts, some of which may be in a desirable and others in an undesirable direction.

Many types of training, coaching, and behavior shaping require continuous split-second decisions and strategic choices as to which instances of behavior and which parameter shifts, to reinforce.

Imaging In Performance

Just as motor programs are created by the act of executing motor routines, imaginal programs[5] are created by the perception of stimuli, i.e., sensory inputs. Examples of imaginal routines are visualization, internal hearing ({P} Reisberg, 1992), or imagining movements (kinesthetic imaging without muscle engagement). There is substantial overlap, often near-identity, of the brain areas involved in seeing a particular stimulus and in visualizing that same stimulus ({P} Kosslyn, 1980, 1994). There is similar overlap in exteroceptive hearing and internal hearing of a certain sound ({P} Naatanen, 1985; {E}

Intons-Petersen, 1992; {E} Smith, Reisberg, & Wilson, 1992).[1]

Imaginal routines are, of course, always covert, though they may be integrated with motor routines. Some imaginal programs encode the effects that were produced by overt motor routines on previous occasions, effects that may have been visual, auditory, kinesthetic, cutaneous, or a combination of these components. Other imaginal programs encode performance models that the learner observed exteroceptively, but is not yet able to achieve.

> In musical performance, imaginal programs provide a model for what the piece should sound like.[2] Another example are the "result" programs that make for uniform and consistent handwriting features regardless of which effector system is employed for writing, as discussed earlier.

Matching Internally Encoded Models

When we speak of imitation, copying, or matching, we usually refer to an <u>external</u> model that is being imitated, copied, or matched ({P} Skinner, 1953; 1957, pp. 55-65). Recognition, a process which is of obvious biological importance, involves the matching of an exteroceptively perceived stimulus to a previously encoded imaginal program ({P} Zentall, Jackson-Smith, & Jagielo, 1990; {P} Lawrence, 1963; {P} Schoenfeld and Cumming, 1963; {P} Cumming, Berryman, & Cohen, 1965; {P} Wright and Cumming, 1971; {P} Watt, 1988).

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[1].The distinction between "visualization", "internal hearing", or "imagining of movements" and other processes is not always clean, nor is it particularly important to our analysis. For example, in a study of the "visualization" processes used by chess masters when they play chess blindfolded (without sight of the chessboard), the chess masters reported that what they visualized was not a clear visual image of the chess board and pieces, but rather an "abstract representation" of these, and of the "lines of force" that are operative in the "visualized" chess positions ({E} Chase & Simon, 1973; {P} De Groot, 1965).

[2] Beethoven wrote all of his later works with the benefit of "internal hearing" only, as he was totally deaf. Most experienced composers do their composing without access to any musical instrument, and orchestral composers obviously don't have access to an orchestra while composing. This internal hearing ability is no different than what we do when we write text and know exactly what it will sound like when later read outloud by a familiar voice.

An important point is that performance learning almost always involves the imitation, copying, and matching of internally encoded models ({P} Schmidt, 1982, p. 131; {P} Keele, 1982, pp. 171-2; {P} Nottebohm, 1970; {P} Newell, 1974; {P} Wrisberg & Schmidt, 1975; {P} Diewart & Stelmach, 1978). These models are imaginal programs that are continuously and instantaneously accessible for imitation and comparison at every moment of the performance learning process.

Creating the Internally Encoded Performance Models

In performance learning, the purpose of observing external models of the desired performance (for example, by watching a master performer) is not to imitate or match or copy such external models directly, but to create or modify <u>internally encoded</u> models. Creating and shaping the internally encoded model of the desired performance is the basic endeavor of performance learning. A good teacher or coach helps the learner build the internal model which the learner then strives to match.

> The Suzuki method of teaching violin playing stresses the formation of internal models of well-played violin music ({P} Pronko, 1969; Suzuki, 1981).
>
> Learning to speak a language without accent and idiomatically depends on hearing it spoken a lot, so that the required templates (internal models of what it should sound like) can develop.

The learner strives to match the internal model by continuously comparing it to the evolving performance. This matching process is maintained by the action of self-generated reinforcements. When the learner is motivated, a perceived improvement in the goodness-of-match is reinforcing. According to the parameter-shift theory of reinforcement, these reinforcements would progressively shift the settings of each sub-routine's parameters in the desired direction.

BASIC TECHNIQUES OF PERFORMANCE SHAPING

Creating Internally Encoded Models

Much of performance technology deals with the process by which the internal models of the desired performance are most efficiently created and shaped. Observation of external models is a common starting point, but, as explained above, the only function of such observation is to shape the internal models.

One of the teacher's or coach's functions is to ensure that the important features of the external models are observed and discriminated, and are incorporated into the internal model. The teacher or coach does this by providing special discrimination training relating to detailed separate features of the external model. For instance, the teacher can point out, to the learner, discrepancies between the emerging performance and the desired one, and provide pinpoint-ed feedback to hone the details of the internally encoded model.

> Before being able to learn to speak in a new language with the right accent, learners may need special training in learning to discriminate certain sounds that are not distinguished in their own language. Only after the internal model of those sounds is in place can they learn to articulate and match those new sounds.

The Importance of Critical Covert Components

Possessing an internally encoded model of the desired performance is not equivalent to having mastered that performance and being able to execute it. Having an internal model of the desired effects is not the same thing as having the motor programs required <u>to achieve</u> those effects.

Nor is having a good internal model sufficient for being able to <u>learn</u> the desired performance. The exteroceptively perceived movements executed by a model performer are only the <u>observable</u> part of the effect to be produced. But, as was explained earlier, every performance consists of a weave of overt and covert routines. The model performer's vital covert routines, being invisible, are not directly perceptible and accessible to a learner who is trying to imitate the model performance. And yet, they are usually critical.

> When learners observe a model performance, whether championship tennis, listening to a famous singer, or playing over a grandmaster chess game, most of the critical and essential behavioral components of the master performance were covert and therefore invisible or inaudible, and unobservable.

In order to imitate a model performance successfully, learners must identify and learn the vital invisible routines too, which requires gaining access to them. One of the important roles of a teacher or coach is to identify and teach the critical covert routines that are invisible in a model performance. The internally encoded model is not fully matchable until it includes those covert routines.

Changing the Internal Model

Perception is a function of prior experience in interaction with contemporaneous sensation ({P} Skinner, 1953; {P} Graham, 1958, p. 911-915). Prior experience (stored as internal encodings) generally overrides contemporaneous sensation ({E} Cumming, Berryman, & Cohen, 1965; {E} Carter & Werner, 1978). Organisms tend to perceive what they have learned to perceive ({P} Woodworth & Schlossberg, 1955, pp. 403-491; {E} Wright & Cumming, 1971), rather than what is really there. As a consequence, internal models tend to override exteroceptive models.

> Familiar examples of this are the persuasiveness of the magician's slight of hand, and optical illusions generally. There is also the often-seen phenomenon of highly persuasive and compelling evidence being ineffective in "changing someone's mind."

This principle can be a problem for performance learning in cases where the existing internally encoded model is inadequate and needs to be changed. The teacher may present the new model, and the learner may see it or hear it, and yet persist in matching the performance to the old internally encoded model, without modifying it ({P} Brown, 1973).

> This typical conversation exemplifies this phenomenon: Teacher: Don't say "He ain't coming." Say, "He isn't coming." Student: I said "He ain't coming."

When the coach or teacher is explaining something to the student, the student can hear the explanation only through the filters and transducers of prior encodings and extant programs. The teacher must be alert to this fact, and focus special attention on discrepancies between what the teacher wants the the student to perceive, and the learner's existing perceptual programs. The teacher must first modify the old encodings in the desired manner. In the above example, the teacher would need to focus the student's attention on the discrimination between "isn't' and "ain't."

> The common teacher-student interaction, "Do you understand?" "Yes" is usually useless at best, and misleading at worst.

The frequent use of that type of student-teacher interaction is due not to its usefulness, but to the comforting illusion of effective communication it creates for the teacher. Understanding can only be ascertained by the evidence of overt performance.

The Use of Metaphors in Coaching

Metaphors are an important tool in performance coaching.

> When coaching a dancer, the coach may say "Slink like a tiger" or "Soar like an eagle." A piano coach may tell the pianist to make a fast passage sound "like a string of pearls" or a ponderous passage "like a march of the ghosts of ancient heroes." Muhammad Ali

counseled boxers to "dance like a butterfly and sting like a bee."

Can such metaphors help shape the learner's internalized models, or are they just manifestations of coaches' idiosyncratic poetic impulses? The concept of equivalence classes[6] ({De, Rev} Sidman, 1986; 1988; 1989) helps answer that question.

Here is how equivalence relations enable the coach to achieve the desired result: The instruction "slink like a tiger," triggers a series of imaginal programs: One of a tiger, one of slinking, and perhaps one that makes imaginal animals move. Those programs are then combined into a new imaginal program of a slinking tiger. Finally, an imitation and matching program switches back and forth continuously between the imaginal slinking tiger and the dancer's own movements as the dancer slinks.

This is a model for the way any metaphor can work, and may be the model for the effectiveness of certain poetic and literary devices, as well as many musical and artistic effects.

Clearly, a metaphor can be effective only if the performer and the coach share the pertinent equivalence classes. Accordingly, the coach must always consider, before using a metaphor, whether the student is likely to possess the relevant concepts and equivalence classes. Even though people who are members of the same culture usually share many equivalence classes, it is still good practice to use two or three metaphors to increase the chances that at least one of them will connect.

Concept Formation

Concept formation occupies a central position in performance learning, as every decision or choice among alternatives is based on previously learned concepts. Having a certain concept means being able to discriminate between certain classes and generalize within those classes ({De, P} Keller & Schoenfeld, 1950, pp. 154-161; {DE, E} Hull, 1920; {E} Smoke, 1932; {P} Mechner, 1967; 1981). Examples (specific instances) of the concept are the members of the classes.

> The split second decision as to whether to use a backhand or forehand swing in a particular tennis situation involves the application of a concept (classification of the trajectory of the ball and the positions of the players).
>
> Moves in a chess game are based on conceptualizations of features of the position[7]. If the learner is not yet able to understand the general case of the concept (e.g., a general statement of a strategic principle in chess), the most effective concept learning procedure is to present the examples (e.g., specific positions that exemplify the principle) before trying to teach the general case ({P} Fischer, Margulies, & Mosenfelder, 1965). Simon & Chase {P}(1973) estimate that it takes ten years to learn the number of concepts needed to play at the international master level.

Since it is usually not known whether any particular learner can already understand the statement of the general case of the concept, it is safest to use the G-E-G (**G**eneral case - **E**xamples - **G**eneral case) strategy. Learners who can already understand the general case will skip the E-G part. The others will learn from the E-G part ({P} Mechner, 1967).

Programs That Manage Other Programs

Some types of skilled performance can be learned quickly by creating programs that organize and manage other programs, as do operating systems in computers. We can call them "managerial" programs. Such managerial programs, once learned, can prioritize the accessibility of other programs or organize or restructure them.

> Mnemonics, for example, are simple managerial programs that can be used to sequence and connect other programs.

> The long division algorithm is another example of a simple managerial program. The long division program is always the same, but the arithmetic programs it accesses for the particular operations required and the numbers that are written down depend on the specific numbers being divided.

An algorithm is also an example of a managerial program. It is somewhat like a template into which other programs can be fitted. Verbally formulated "principles," "rules," and "strategies," can function like complex algorithms ({P} Landa, 1974). Algorithms, whether verbal or non-verbal, often form part of the performance. An algorithm that has been learned is usually a chain or branching chain ({P} Mechner, 1981) that is used to retrieve and marshall other programs according to the requirements of the specific situation in which the algorithm is applied.

> Skill at strategy games like chess or go requires the learning and utilization of highly complex systems of algorithms. Good teachers and coaches teach algorithms that become covert with practice ({P} Mechner, 1981).

Managerial programs can function as the initial scaffolding for the assembly and organization of newly learned programs, and thereby determine the course that the learning of a performance skill will take. In that sense, they are the basis for learning skill, for differences in learning style, and for the idiosyncratic ways in which different people approach problems and learning situations.

Covert Practice Can Be Effective

Covert (sometimes called "mental") practice of skilled performance is often effective. A review of the literature suggests that it is least effective for programs that are overt in the target performance, and most effective for programs that are themselves covert in the target performance ({P} Ryan, Blakeslee, & Furst, 1986; {P} Ross, 1985; {P} Heuer, 1985; {P} Ryan &

Simons, 1983). "Results" programs, for example, are always covert, and can benefit from being practiced covertly. The practice of "visualization" as a self-management or auto-therapeutic technique relies on that principle.

> Musical performers often explore covertly new ways of interpreting a passage ({P} Lhevinne, 1924/1972; {P} Slenczynska, 1961, p. 121; {P} Hoffmann, 1909/1976, pp. 23-24, 52-53; {P} Shaffer, 1981; {P} Kohl & Roenker, 83). Executing these covert routines creates new internalized models of the desired performance, models that can then be matched as the required new performance skills are practiced.

A performance skill can also benefit from covert rehearsal of algorithms that form part of the final desired performance. Finally, covert rehearsal of normally-overt routines can serve the function of assembling all of the needed sub-routines into the fast-access memory resources preparatory to performance ({P} Sandor, 1981, p.190).

Emotional reactions too can occur covertly and can therefore be manipulated by imaging them ({P} Glenn, 1977; {P} Cautela, 1971; {P} Cautela & Kearney, 1986; {P} Wolpe, 1978). Rehearsal of imagings of a successful result, prior to performance initiation, can generate emotional states that motivate and energize the performer.

Covert practice is least effective for skills that involve delicate muscle coordination and utilization of kinesthetic cues.

PERFORMANCE ECONOMY AND EFFICIENCY

Coordinative Linkages

There are hundreds of muscles in the body, and most movements use dozens of them in coordinated and intricately phased relationship with each other. If each muscle had to be controlled separately each time a complex movement is executed, skilled performances would be unlearnable and unmanageable.

The problem is solved in much the way engineers have made automobiles manageable to drivers, and computerized word-processors to writers.

> If the driver of an automobile had to control and orient each of the four wheels separately at every moment, few cars would go very far. Engineers solved this problem by linking the wheels mechanically. So, the driver controls the orientation of all four wheels by operating only one steering wheel.

The physical design of the human body has many purely mechanical linkages that permit the contraction of only a few muscles to produce an elaborate result. The architecture of the spine, knee joint, and the interconnections of the tendons in the hand, are familiar examples.

But coordinative linkages do not have to be mechanical. They are can also be used in logical systems, as in computer software.

> Word processing would be difficult or impossible if it had to be done in computer language. Word processors are made "user friendly," by providing single keystrokes that activate sub-programs consisting of dozens of coordinatively linked pre-programmed commands.

Coordinative Structures for Movement

Motor routines are generally executed by linked muscle groups that work cooperatively. The linkages are both mechanical (at the joints and tendons) and neural ({P} Normand, LaGasse, & Rouillard, 1982). The neural linkages may be innately and anatomically set at birth, or the result of learning. We will be applying the term "coordinative structure" (Bernstein, 1967) both to mechanically linked physical structures, and to behavior programs that are permanently or semi-permanently linked neurally.

Familiar examples of innate "hard-wired" neural linkages are those for maintaining body balance, walking, and running. Many of these are encoded at the level of the spinal cord rather than at the cortical level. Others are encoded at the cerebellar level ({P} Normand et al., 1982). The interconnections of motor programs within the spinal cord function almost like specialized independent brains. Because of the existence of such spinal control centers, a decorticate cat can still walk and adjust its gait when a foot bumps into an obstacle ({E} Forrsberg et al., 1975), and a decorticate dog can still scratch itself (REF).

Degrees of Freedom

The types of linkages described above reduce the system's degrees of freedom, which we will abbreviate as "DF". DFs can be thought of as the number of separate decisions that need to be made in executing a complex routine. The fewer DFs there are in a system, the fewer decisions are required to operate it and the easier it is to manage. In body movement, in the absence of linkages or constraints, every little muscle at each joint would have to be separately controlled and would represent one potential DF. The linkages reduce the number of DFs required. Mechanical and neural linkages permit complex and elaborate behavior patterns to be generated by a small number of neural "decisions" ({P} Turvey, Fitch, & Tuller, 1982; {P} Turvey, Schmidt, Rosenblum, & Kugler, 1988; {P} Belen'kii et al., 1967).

Degrees of Freedom in Performance Learning

There are limits to the number of DFs that can be managed for any skilled performance. That is why the learning of a performance skill involves a constant battle to keep the number of DFs down. As new routines and effector systems are brought into play, the number of DFs would naturally tend to increase. To keep their number from increasing, the new routines must be linked into coordinative structures.

The result of keeping the number of DFs manageably low, prior to the establishment of new coordinative linkages, is rigidity and lack of adaptive flexibility. In the early stages of learning a performance skill, the learner can maintain control (i.e., keep the number of DFs manageably low) only by a slow and stiff performance that uses a limited number of muscles. As the learning process proceeds, the learner gradually replaces the initial rudimentary coordinative structures with the new more elaborately linked ones, one by one, as they are mastered. As more effector systems become linked, the performance becomes more flexible, graceful, and effective. But as this happens, the number of DFs (and the number of coordinative structures involved) need not change ({P} Turvey et al., 1982, p. 254).[8]

Increasing Control Without Increasing the DFs

Coordinative structures can vastly reduce any movement's DFs while at the same time increasing the number of routines and effector systems that participate. In learning motor skills generally, control is increased by increasing the number of muscle systems that participate in the execution of the skilled performance, without increasing the number of DFs. Additional muscle systems, as they are brought in, can compensate for each other in a flexible and adaptive manner ({P} Tuller, Fitch, & Turvey, 1982).[9] Entire complex routines come to function as units.

> In piano learning, for example, playing a single note with the proper finger, hand, and arm coordination is such a unit.

> A skilled juggler does not make a greater number of decisions than a child tossing and catching a single ball. He also does not expend a larger amount of effort. The juggler has built up elaborate coordinative structures that constrain and minimize his movements and decisions.

An important class of coordinative linkages are those between eye movements, and certain body movements like reaching, walking, or striking.

> In karate, the student learns to maintain eye contact with the opponent, because his own and the opponent's eye movements, being coordinatively-linked antecedents of certain body movements, would provide advance warning of punches. In non-human species too, eye contact is often associated with aggression for the same type of reason.

In summary, skilled performances are built by the establishment, through learning, of new neural linkages among programs -- linkages that form new coordinative structures.

Coordinative Structures in Perception

The efficiency of perception too depends on coordinative structures. For example, the basic vocabulary of vision consists of edges, symmetries, repetitions, gradients, flow patterns, orientation, and other types of regularities ({P} Witkin & Tenenbaum, 1983; {P} Treisman & Gormikan, 1988). These vocabulary elements are due to the anatomy and neural linkages of the visual system ({P} Livingstone & Hubel, 1988; {P} Felleman & Van Essen, 1991; {P} DeYoe & Van Essen, 1988; {P} Wiesendanger, 1990), with learning playing a relatively minor role. Konorsky {P} (1967) believes that there are nine separate hard wired neural systems for recognition of various categories of objects, such as small manipulable, large mobile, faces, etc.

> There are individual neurons that are specialized for very fast (80-160 ms) recognition of complex visual patterns that have particular biological importance, like primate faces ({E} Damasio, 1989; {E} Leonard, Rolls, Wilson, & Buylis, 1985) or primate hands ({E} Gross, Rosha-Miranda, & Bender, 1972).

Efficient audition too is due to coordinative linkages. Some neurons respond selectively to certain sound frequencies, overtone patterns, and frequency changes. Other neurons respond only to the onset of tones, others only to their termination, others to either onset or termination, and yet others only to sounds that emanate from certain directions ({Rev, E} Reisberg, 1992).

Coordinative Structures of Covert Programs

Coordinative linkages are not only mechanical or sensory. They also exist in logical systems.

> A language's syntax is, in effect, such a system of linkages and constraints. The language user's programs for syntax reduce the degrees of freedom, and hence the number of choices the user makes in selecting and positioning the words of a sentence. Similarly, the richer and more varied a speaker's library of syntactic programs, the greater the flexibility with which he can adapt the sentence to the "result" program that initiated the sentence, i.e., the desired effect that the sentence is to have on the listener or reader.

It should be noted that syntactic constraints and coordinative structures are necessary not only for the production of language, as in speech and writing, but also for <u>decoding</u> language, as in listening and reading.

Economy and Efficiency of Performance

One reason why expert movements are more economical is that they use more elaborate coordinative structures ({P, E} Ortmann, 1929, pp. 78, 99). The greater the number of muscles that participate in the performance and cooperate in sharing the work, the less work each muscle needs to do ({P} Schultz, 1936) and the less effortful it is. That is why an expert performance, whose appropriate coordinative structures are in place, is relatively effortless, economical, and effective.

> An experienced waiter can walk fast and gracefully while carrying a heavy loaded tray, while an inexperienced person would need to walk slowly and stiffly when carrying it.
>
> A seventy year-old martial arts master, whose movements are cooordinatively linked in an efficient manner, can often throw and defeat a much stronger and younger opponent.

This principle also applies to verbal behavior and to covert routines.

> A highly trained speaker of a language can effortlessly emit syntactically complex sentences, while a child or a foreign speaker may struggle with relatively simple syntactic structures. The difference, again, lies in the elaborateness of the available coordinative structures.

Conceptual Frameworks are Coordinative Structures

In performance learning, conceptual routines too become organized into structures or systems that are constrained by linkages. We sometimes refer to these systems as "conceptual frameworks" and "associated ideas."

> Strong chess players consider only a few moves in any given position, because their conceptual frameworks reduce the degrees of freedom (and therefore the number of decisions) for selecting the moves to be considered.
>
> Covert conceptual coordinative structures constrain the choices in other types of skilled performance too, including tennis, karate, dance, and musical performance.

Thus, the formation of new coordinative structures in motor programs, in covert programs, in perceptual programs, and in concepts, is at the core of performance learning. The learning of a skilled performance is partly a matter of defining and determining the architecture of the coordinative structures that need to be learned. Defining and determining them is one of the performance teacher's main functions.

Practicing Sequences of Positions

Another reason why expert movements are smooth and economical is that they minimize the number of sharp changes of direction. There is evidence that motor programs do not register and store movement as continuous motion, but rather as sequences of discrete positions, just as a motion picture film registers only sequences of still frames ({P} Schmidt, 1982, pp. 219-221; {P} Feldman, 1966, 1986; {P} Kelso, 1977; {P} Schmidt & McGown, 1980; {P} Keele, 1982, pp. 184-5; {P} Tuller, Fitch, & Turvey, 1982, pp. 265-267; {P} Polit & Bizzi, 1978). When the motor routine is then executed, the body parts involved move smoothly from one discrete position to the next, passing through each position without pausing. The motor program does not, and does not need to, specify the movement trajectory from one position to the next, just the positions themselves.

It is likely that motor programs store the positions that occur at the "movement corners," where the movement changes direction most rapidly, and where energy bursts are therefore required. To achieve smooth and economical movements, it may be efficient to identify and practice the body positions that occur at those points, and, like the expert, to devise movements and coordinations that minimize the number of sharp changes of direction.

PERFORMANCE MISTAKES: INVALID COORDINATIONS

Valid and Invalid Routines

The term "valid" refers to movements and coordination patterns that will be serviceable in the final performance at the desired speed, and the term "invalid" refers to any that will <u>not</u> be serviceable. The challenge in learning and practicing a performance is to practice only valid movements and coordinations, and to avoid practicing invalid ones ({P} Ortmann, 1929, p. 78, 80, 102-105, 271-273, 291).

> Ortmann showed that in executing leaps between two distant keys on the piano keyboard, the hands of accomplished pianists describe a smooth parabolic trajectory skewed toward the target key, while those of less experienced pianists tend to describe a more jagged trajectory as the hand hovers over the target key to ensure accurate landing. Jagged movements are not serviceable in the fast execution of leaps, and are, in that sense, invalid.
>
> Other examples are twisting the hand to bring the fingers into position, and lifting fingers too high. Different types of passages, such as arpeggio passages, runs, and octave passages, each invite different types of invalid coordinations. For example, in playing the C major scale, the thumb, second, and third fingers play C, D, and E respectively. Then comes the F, played by the thumb passing under the second and third fingers. When the scale is played fast, the thumb should already be on its way to the F when the second finger is playing the D, and should be fully positioned over the F when the third finger plays the E. But when practicing the scale slowly, there is plenty of time to bring the thumb to the F after the third finger has played the E. The result is an invalid sequence of positions that is not serviceable when sped up, and must be unlearned and overridden before the scale can be played fast and smoothly. The same problem occurs in arpeggios, which can be thought of as expanded scales ({P} Ortmann, 1929).

Executing an invalid routine sets back the learning process, because it creates or strengthens a program that will later have to be overridden. By practicing only the movements and coordinations that will be efficient and economical when the passage is played fast, the learner creates valid motor programs that will be serviceable even when sped up, and that will not need to be overhauled at some point along the way as speed is increased.

The Importance of Avoiding Mistakes

Routines that have been practiced, regardless of whether they are wanted or unwanted, valid or invalid, remain stored as programs ({P} Kochevitsky, 1967 p.50; {P} Gieseking & Leimer, 1972 p.47). An invalid routine therefore amounts to a "mistake" ({P} Whiteside, 1955, p.48). Invalid programs, once created, are difficult or impossible to eradicate completely. "Mistakes" can resurface unexpectedly, often when they are not desired, especially under conditions of tenseness, stress, or anxiety, a phenomenon called "regression" or "resurgence" ({P} Mowrer, 1940; {P} Masserman, 1946; {P} Epstein, 1985; {P} Mechner, 1992; {E} Mechner, Hyten, Field, & Madden, 1992; {P} Mechner, 1992).

> For a musical performer, a certain long-abandoned mistake may no longer occur under the calm conditions of practice, but will reappear under the stress conditions of a public performance when the performer is experiencing performance anxiety or "stage fright."

The effect of practicing a mistake cannot be reversed by a verbalization like "That was wrong" or "I mustn't do it that way." Motor programs don't understand English and therefore cannot be controlled or edited by words alone. At the neural level, the mistake is learned just by virtue of the fact that the mistaken routine was executed ({P} Kochevitsky, 1967 p.50; {P} Gieseking & Leimer, 1972 p.47).

Performance Mistakes in Covert Routines

Mistakes are not confined to playing wrong notes or failing to get the ball over the net. They need not be overt. They can also occur in covert and verbal behavior routines. Teachers and coaches often call such mistakes "wrong thinking."

When mistakes occur in covert behavior, and are therefore invisible, it is more difficult for a teacher or coach to provide quick and unambiguous feedback. Also, covert mistakes do not receive the same fast and pinpointed physical feedback that overt routines receive from their physical effects on the environment. Mistakes in covert routines usually have more delayed consequences than mistakes in overt routines.

> In games like chess, where most of the performance routines are covert, the player may not experience the consequence of a mistake for many moves, and may therefore never "make the connection" between the bad move (which was generated by erroneous covert routines) and its consequence.

Although interpersonal interactions in social or business situations are not usually regarded as performances, "mistakes" made in interpersonal interactions, where feedback tends to be quite imprecise or misleading, often have some of the same properties as performance mistakes. The same mistakes, especially when they involve erroneous thinking, may persist for a long time, or even permanently. Like overt mistakes, covert mistakes of these types also will resurge under conditions of anxiety and stress, and are best corrected by a discerning coach.

Can One Learn From Mistakes?

Many performances depend on concept formation. As was explained earlier, even interactive performances, like tennis, chess, or a martial art, depend on learned concepts. Concept learning always involves the acquisition of discriminations, i.e., learning to classify and respond appropriately to instances and non-instances of a class ({P} Mechner, 1963, 1967, 1968, 1981). That is why errors that are immediately classified as such and receive immediate feedback, can promote the formation of conceptual classes. Learning explicitly which is the right way and which is wrong way may help the performer avoid the wrong way. That is the type of learning-from-errors to which Schmidt refers in describing his schema theory ({P}
Schmidt, 1982, pp. 229-30).

But the process of teaching the learner to recognize and classify right and wrong instances need not and should not utilize punishment. Negative feedback that amounts to punishment of mistakes is always detrimental to performance learning, because punishment has emotionalizing and sometimes anxiety-producing effects. When mistakes become too unpleasant or painful, aversion spreads to the entire performance. The performance may then become depressed or disrupted ({P} Azrin & Holz, 1966, pp. 439-40), and the learning process set back. A skillful coach knows how to provide negative feedback in non-punishing ways.

The problem with permitting errors to be made with a view to promoting concept formation is that such errors, when practiced, are, to some extent, learned. The learner may have learned to state verbally that a certain way of doing it is wrong, but motor programs don't respond to language. They are affected only by the performance of routines. So, every time the erroneous routine is executed, the likelihood of its future resurgence is increased. That is the price that learning from errors exacts, a price of which both teacher and student should be aware.

Errorless learning, on the other hand, though technically possible, has its drawbacks too. It does not promote concept formation. Errors that have never been made may be difficult to avoid when they are later unexpectedly prompted by some uncontrolled stimulus in the performance situation.

Plateaus in Performance Learning

Performance learners often "hit plateaus" in their progress when they initially learn and practice routines and coordinations that produce quick results, but that later prove to be dead ends in the road to further progress ({E} Bryan & Harter, 1897, 1899).

The correct "form" for the tennis backhand stroke may not send the ball over the net in the

> initial attempts, whereas a makeshift incorrect form may do so. Thus, when learners opt for fast results, they often practice and learn bad form that they will later have to unlearn if they wish to make further progress.

Another familiar circumstance that leads to plateaus is outside pressure to accomplish tasks or achieve practical results quickly, as on a job, so that extended learning stages are impractical or unaffordable.

> Users of word processing software often make do with a limited but sufficient set of commands, and don't take the time to learn a larger and more efficient set that would ultimately produce better performance ({Rev} Ashworth, 1992).

Avoiding Plateaus

Plateaus in performance learning can be avoided by learning ultimately valid coordinations early in the learning process. This generally requires guidance from a teacher and deferral of the gratification that quick results can provide. In certain skills like receiving Morse Code, learning plateaus can be avoided by the use of instructional programs that prevent the development of invalid behavior patterns ({E} Keller, 1958).

"Layoffs" of weeks, months, or years, can be useful for "getting out of a rut" (abandoning dead-end coordinations or inadequate internal models) and making a progress spurt. During such layoffs, previously-learned coordinations and internal models often become weaker, making it easier to replace them with new and more serviceable coordinations and models. This principle is equally applicable to overt and covert aspects of performances.

> In games like chess or go, where "wrong ways of thinking" can impede progress, a layoff can often result in a progress spurt at the time of resumption. And in interpersonal social or business relationships, a long separation between two individuals can change the relationship for the better.

Superstitious Routines

All performers incorporate all kinds of superstitious routines into their performances. A superstitious routine is one that serves no function and has no desirable effect on the performance.

> A familiar example is a bowler's elaborate pattern of follow-through and posturing for two or three seconds after release of the ball. Normal follow-through movements often become superstitiously integrated into the performance as elaborated flourishes that take on a life of their own. Another example is a pianist's massaging of a piano key after the key has been fully depressed, or making vigorous weaving motions of the body, or head-tossing movements.

Superstitious routines become established as a result of occasionally being followed by desired consequences, though the connection may be non-causal and coincidental. Even when the sequential relationship between the routine and its occasional consequence is merely contiguous rather than causal, the effect is behaviorally similar to what it would be if the relationship were truly causal ({E} Skinner, 1948; {P} Skinner, 1953; {P} Herrnstein, 1966).

Superstitious routines in performance range all the way from the extreme cases cited above, to micro-patterns we could call idiosyncratic or stylistic, such as the myriad incidental features of our handwriting, or ways of speaking and gesturing.

Managing Superstitious Performance Routines

In performance technology, we are concerned primarily with the superstitious routines that compete for the limited resources needed for the desirable coordinations, and thereby interfere to some extent with the functional routines. When superstitious routines are executed repeatedly, they become integrated into the programs that constitute the performance. To the extent that such superstitious routines then burden the resources needed for the desired economical and efficient performance, they must be considered a type of performance mistake.

The performer's, teacher's, and coach's continuous task is to remain alert for dysfunctional superstitious routines and continuously "clean up" the performer's internal performance model so that it does not come to include such routines. The most difficult part of this task is to distinguish truly dysfunctional routines from those that represent the natural and efficient "follow-through" of a coordinated movement. Follow-through is the inertial effect of moving a mass efficiently. Chopping off a follow-through movement too abruptly can introduce extra energy-consuming "movement corners" into the routine, thereby making the routine less economical.

The above discussion of superstitious routines emphasizes overt motor routines. But far more insidious are the covert superstitious programs that become integrated into performance programs. These are obviously much harder to detect and correct, and yet their detrimental effects on the performance can be just as great or greater. Covert superstitious routines can include dysfunctional ways of thinking and entire program hierarchies.[10]

Ways to Practice Mistakes Inadvertently

Performers often continue to practice when they are tired without realizing that to practice when tired is very likely to cause backsliding.

The movements of fatigued muscles are not the same as the movements of rested muscles ({P} Ortmann, 1929, p.79). But the motor programs register all movements, regardless of whether the muscles that execute them are rested or tired. Fatigued movements get registered just as surely as rested movements ({P} Hoffmann, 1909/1976). The resulting invalid motor programs will later have to be overwritten, an extremely difficult and inefficient process. That is one reason why practicing when tired amounts to practicing mistakes, and is counter-productive.

The other reason, discussed later, is that a tired learner will not be able to monitor the performance with great alertness or energy, and will therefore be inefficient in the process of matching the internalized model.

Successive Approximations

Complex performances are often learned by a process of gradual, successively closer approximations to the final desired performance ({P} Skinner, 1938; {P} Keller & Schoenfeld, 1950). The challenge in performance learning is to find and use approximation paths that lead to the goal in a continuous sequence of properly sized steps, without big discontinuities, starting from a repertory of building block component routines that the learner can already execute.

For many types of performance, performance speed can be used as such an approximation path.

> Pianists, when learning a new passage, are often able, already at the outset, to play the passage accurately by playing it extremely slowly, with each hand separately. The task is to learn to play it at the desired faster speed, in the desired way, with both hands together. It therefore seems reasonable to learn the new piece by gradually increasing the speed ({P} Slenczynska, 1968, pp. 30-31; {P} Sandor, 1980, p. 45, 71, 185-186).
>
> But it's not that simple. The problem is that when pianists play a passage slowly while maintaining the correct rhythm, they cannot and do not make all of the same movements in slow motion.

Using Pauses To Create Successive Approximations

Routines executed in slow motion tend to be invalid because the muscle tension levels (agonist-antagonist tension ratios) and coordinations, as well as the external reactive forces (like inertia, physical impacts, and gravity), are different than when the routines are executed fast ({E, P} Ortmann, 1929, p. 102-105, 160-171, 283, 291; {P} Schultz, 1936, pp. 13-30; {P} Kochevitsky, 1967; {P} Sandor, 1980, p.71; {P} Turvey et al., 1982, p. 250). The relative tension levels of the agonist-antagonist muscle pairs depend on movement speed: The slower the movement, the more nearly equal those tension levels are. The faster the movement, the more different they are. Therefore, slow movements create different motor programs than fast ones.

> An additional practical problem in piano playing is that if a pianist played a passage in slow motion, no sounds would be produced, because the keys would go down too slowly to propel the hammers against the strings. Since pianists usually want to produce sounds, even when playing slowly, they depress each key with at least the speed and force they will use at the ultimate playing speed. Thus, the slowdown is achieved by increasing the time intervals <u>between</u> key depressions.
>
> Dancers can slow down a dance routine by pausing between consecutive leaps or steps, but the speed of the individual leaps or steps is set by gravity.

Therefore, it is best and more practical, to slow down a routine by executing it as a sequence of fast movements separated by pauses ({P} Slenczynska, 1968, pp. 30-31; {P} Sandor, 1980, p. 45, 71, 118, 185-186; {P} Kochevitsky, 1967, p.26; {P} Schick, 1982, p.43; {P} Young & Schmidt, 1990).

Selecting Proper Pausing Points

The points at which the pauses are inserted have a permanent effect on the performance, as pausing points define musical modules that can function like phrases. As the pauses are gradually eliminated, the pausing points become the demarcation points of the modules. Those demarcation points continue to have a residual effect on the performance long after the modules have become fused into larger units with all pauses eliminated.

That is why the pausing points used during practice must be selected with attention to the music's rhythms and phrasings.

> In singing, reciting lines, or playing wind instruments, one of the important things that the performer must learn is when to take breaths. Taking a breath has an audible effect on the performance: It not only produces a break in the continuity of sound, but also affects the execution of the routines that follow. For example, greater volume can be achieved immediately after a breath has been taken.

In any practicing routine, pauses come to define modules that can function like phrases.

> When a piano passage is practiced at increasing speeds, and the pauses are gradually eliminated, the cleavage lines along which the modules can still split apart, remain at the original modular boundaries. For example, if the pianist, during a performance, varies the musical interpretation (as pianists normally do) by means of slight rhythmic distortions consisting of small accelerations, decelerations, and hesitations, the original modules, as defined by the pausing points, reassert themselves.

That is why the pausing points used during practice must be selected with attention to the structure of the final desired effect, be it music or any other art form. When it is music, the pausing points would normally be based on the music's rhythms and phrasings.

MAKING THE PERFORMANCE ULTRA-STABLE

Cues in Skilled Performance

The routines comprising a skilled performance are triggered by cues of external or internal origin. Cues can also interrupt ongoing routines and restart them, or replace them with new ones. Walking, for example, is a recycling motor routine ({Rev} Grillner, 1981). If a foot hits an obstacle, the resulting feedback cues interrupt the ongoing motor routine and trigger a new one ({P} Quinn and Sherwood, 1983; {P} Gallistel, 1980; {E} Shik and Orlovskii, 1976). The new one may be a coordinated equilibrium readjustment of the whole body and a rapid shift of the weight to the other foot ({P} Forssberg, Grillner, & Rossignol, 1975).

The cues are often visual, kinesthetic ({P} Roll, Gilhodes, Roll, & Velay, 1990), auditory, or generated by the performance's own covert routines, i.e., they originate inside the nervous system.

> For example, striking a piano key produces a cue that includes auditory, tactile, visual, and proprioceptive components generated within the muscles, tendons, and joints involved in the movement.

While every cue can thus be thought of as a compound cue -- a collection of component cues, we will continue to use the simple term "cue."

Visual and Auditory Cues

Exteroceptive visual cues are usually important in the early stages of learning a performance, and remain important as a source of feedback in monitoring it.

> Instrumentalists generally look at their hands and fingers and at the instrument when they play. The resulting visual cues are useful and normally become components of the

> compound cues that trigger the performance's motor programs.
>
> A pianist, when practicing a leap to a distant key, just prior to actually executing the leap, will usually look at the key on which the finger is to land and at the finger. With practice, the visual cues thus obtained come to supplement the kinesthetic cues in triggering the motor program for the leap, and also provide visual guidance that can increase its accuracy.[11]

It should be noted that kinesthetic and auditory cues are received automatically, while visual cues are not received unless the eyes are appropriately oriented and focussed. Using visual cues is therefore more time-consuming. A visual cue is received only after the motor routines for eye orientation and focussing have been initiated and executed. No such motor routines are required for the receipt of auditory and kinesthetic cues.

For a music performer, the sound generated as the music is being played can constitute an important part of the compound cue that triggers each successive motor routine during the performance.

> For example, auditory cues are generally very important as a source of feedback for volume and tone control. A pianist relies on them for continuously adjusting the force with which the keys are depressed, particularly during the early stages of learning a performance. Auditory cues are also important in learning to control rhythm and articulation[3] while practicing. Rhythm and articulation both depend on precise timing of key depressions.

Kinesthetic Cues

Kinesthetic cues have a special status in the performance of motor routines. Such cues are produced by body movements and by gravity, and include both proprioceptive and tactile components. Tactile cues are generated when a body

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[3] The term "articulation" usually refers to the combined effect of the evenness of the time intervals between notes, the holding times of notes, and the loudness of each note.

part such as a finger, hand, arm, cheek, or tongue, touches or rubs against adjacent skin, body parts, or physical objects, or when a foot hits the ground. Most body movements generate both proprioceptive and tactile cues, which is why we use the term "kinesthetic" (which literally means "pertaining to the sensation of movement") for the combination of the two. Motor programs are triggered by kinesthetic cues much faster than by any other kind of cue ({P} Kelso, 1982, p.48; {E, Rev} Roll, Gilhodes, Roll, & Velay, 1990). Proprioceptive cues originate in the muscle spindles, which is as close to the instant of the movement as one can get. Because kinesthetic cues emanate from the movements themselves, and in that sense provide direct and immediate feedback, they permit more precise control than other cues do.

As the performance is learned and takes shape, kinesthetic cues become increasingly important in relation to other types of cues ({P} Marteniuk, 1986; {P} Ortmann, 1929, p. 65).

Making Cue Sources Redundant

During any performance, there exists the hazard that one of the cue sources on which the performance depends becomes momentarily unavailable, with the result that the performance is disrupted. That is why a performance can be made more resistant to disruption by making each cue source redundant. A cue source is redundant if it is unnecessary and dispensable, meaning that the performance can proceed without it.

Any given cue source can be made redundant by practicing without access to that cue source, so that the cue source becomes dispensable, and the remaining cue sources sufficient.

> In learning a piano passage, visual cues can be made redundant by learning to play the passage without looking at the fingers or keyboard ({P} Schick, 1982, p. 62; {P} Matthay,

1932, p.82). Postural cues can be made redundant by varying the height of the piano bench or the position of the body ({P} Slenczynska, 1961, pp. 59-59; {P} Hoffmann, 1909/1976, pp. 44-45). Cross-cues between concurrent routines (like the left hand cuing the right hand or vice versa) can be made redundant by learning to execute each concurrent routine separately. And kinesthetic cues can be made redundant by learning to play from any point in the middle of a piece without the benefit of the kinesthetic cues from the immediately preceding passage.

Making Coordinative Structures Redundant

Particular coordinative structures can be made redundant by learning to produce each desired performance result by means of a variety of inter-changeable and equally effective coordinative structures. If something goes wrong with one coordinative structure, or the prevailing circumstances don't permit a particular one to be used, another one can instantly compensate or take over. That way, each routine is made redundant ({P} Shapiro & Schmidt, 1982; {P} Wulf and Schmidt, 1988, {P} McCracken and Stelmach, 1977; {P} Catalano and Kleiner, 1984; {Rev} Schmidt, 1988, pp. 391-395).

Pianists often benefit by practicing a repetitive passage using a variety of alternative coordinations and muscle systems, so that when one muscle system becomes fatigued during a performance, another system can take over ({E, P} Ortmann, 1929, p.79; {P} Hoffmann, 1909/1976).

Some prominent piano pedagogues have advocated practicing piano passages with "wrong" accents, i.e., accents placed at points in the passages where there will be no accents in the final performance ({P} Slenczynska, 1961, p. 47) or varying the rhythms that are practiced, including "wrong" rhythms ({P} Kochevitsky, 1967, p. 41, 50; {P} Schick, 1982, p.29). A disadvantage of this technique is that it programs faulty routines, thereby increasing the likelihood of unwanted accents or rhythmic distortions in the final performance ({P} Sandor, 1981, p.184). The countervailing advantage is that the repertory of available coordinations and motor resources on which the performer can then draw is thereby broadened and made more versatile.

> Tennis players practice a variety of ways of hitting the ball (backhand, forehand, and variations of each) so as to create a large repertory of coordinative structures to permit flexible adaptation to any circumstance that may arise.

Variability during practice can increase the adaptive flexibility of the performance. The inevitable unpredictable changes in the performer's body and environment create varying circumstances to which the performance must adapt. The performer may also want to vary the performance from one time to the next for artistic or other reasons.

"Getting Stuck" in the Middle of a Passage

One of the common specters that haunt performers (especially musical performers and actors) is the fear of getting stuck in the middle of a passage —being unable to continue. This common type of occurrence is often called "memory lapse." It is experienced even by top performers, and is, in most cases, the result of the unexpected intrusion of a cue or of an interfering routine, due to resurgence, that interrupts the performance routine. The present analysis of skilled performance provides an explanation of this phenomenon, along with a cure that flows from that explanation.

A skilled performance is a fused chain of routines that were initially separate, and gradually became fused as a result of practice. As the performance takes shape, the learner normally loses the ability to execute each individual component routine (chain component) separately. The more the fused chain is practiced, the more difficult it is to execute the original separate routines individually. Each separate component becomes dependent on the cues from the preceding components, mainly the kinesthetic cues. Therefore, when interrupted in the middle of such a fused chain, there is no way to cue a resumption from that point forward.

How To Avoid "Getting Stuck"

This analysis suggests that the likelihood of "getting stuck" or "memory lapses" can be greatly diminished by preserving the ability to call up and execute the separate component routines from a "standing start" even after the chain has become fused. The performer must practice in a way that will preserve his ability to do so without the help of the kinesthetic cues from the immediately preceding movements. From the standpoint of performance quality, fusion of the performance chain is desirable and necessary. But it is not desirable also to lose the ability to call up and execute the individual sub-routines that comprise the chain, in case of need.

> For example, without special practice, a pianist may find it quite difficult to start a piece from the middle. To remedy this problem, the kinesthetic cues normally provided by the immediately preceding movements can be made redundant (unnecessary) by learning to start from any point in the middle (so that there are no cues from immediately preceding movements).

Having separate access to each sub-routine in case of need gives the performer an exceptional sense of security and control. If the performance is momentarily interrupted due to any cause, it can restart instantly, seamlessly, and without interruption, from the point at which the interruption occurred, thereby avoiding any disruption. And just as beneficial is the sense of confidence that derives from the performer's awareness of that ability.

Benefits of Redundancy

In general, built-in redundancy makes a performance more flexible and adaptable, less precarious, and therefore more resistant to disruption. Redundancy also provides the advantages of cue-source summation, which the performer experiences as a sense of security and control: If each of several sets of cue sources and routines is sufficient and effective by itself, then the combined action of several is more effective and reliable than the action of any one of them alone. It's the same principle as four-wheel drive. In four-engine aircraft design, every engine is redundant.

One of the effects of increased cue redundancy is to reduce tenseness and performance anxiety, because a performer who does not fear disruptions or memory lapses will be less anxious and calmer, and will have more energy to apply to the artistic aspects of the performance ({P} Whiteside, 1955, p.63; {P} Slenczynska, 1961, p. 121).

MISTAKES DUE TO CUE GENERALIZATION

Cue Generalization Problems

Sometimes a compound cue within a chain is confusingly similar to another compound cue that occurs in another part of the same chain, with the result that the wrong continuation is triggered ({P} Keller & Schoenfeld, 1950, pp. 205-207; {P} Keele and Summers, 1976). A familiar example of such cue generalization is the tongue twister. Spoken words are chains of routines executed by the speech apparatus, where each routine is triggered in part by cues from the preceding routine.

> A tongue twister contains repeating cue patterns that are so similar each time they recur that they sometimes trigger the wrong continuation. Many types of piano performance problems are due to the operation of that same mechanism, with the difference that the cues are generated by the playing routines rather than by speech.

Cue generalization problems can involve very short loops, where the cues being confused recur within one or two seconds (as in the tongue twister), or they can involve long loops, as when a long passage is repeated but has a different continuation each of the two times.[12]

Managing Cue Generalization Problems

The problem can be cured by practicing the chain with pauses inserted at strategic points. Those pauses tend to reduce the dependency on the cues that would normally be generated by the immediately preceding routines, and to supplement these cues with new additional ones. As the pause lengths are gradually reduced to zero, the resulting new modules, triggered by new cue sources, are preserved in the programs that form as a result.

> For example, to master the tongue twister "She sells sea shells by the seashore", the pausing points during practice should be made before "sells," "shells," and "shore." Pauses at those points break up the multiple "sh-s" and "s-sh" sequences that are subject to confusion. As the pause lengths are gradually reduced to zero, the resulting new modules are preserved in the programs that form as a result. Try it by doing it twenty times, with gradually shorter pauses.

The "tongue twister" phenomenon is not confined to the motor level, and does not depend on kinesthetic cue similarity only. It can also occur at a completely covert level, a level where there is no vocalization or muscle engagement at all, and where there are no kinesthetic cues ({P} McCutchen & Perfetti, 1982), i.e., where all of the cues originate within the nervous system. Stuttering may be a cousin of that phenomenon.

It should be noted that when cue confusion occurs, choosing the incorrect continuation is not the only kind of problem that can occur. More common is hesitancy as to which of the two continuations to choose, or simply an increase in tension.

In solving long-loop generalization problems, the performer can use the pausing technique to incorporate into the performance special discrimination-oriented covert verbal routines, like "this is the first time around" and "this is the second time around", or other covert routines that serve the same function, thereby supplementing the confuseable kinesthetic or other cues. Such covert routines enhance discrimination by highlighting differences between the confuseable cues.

Another type of solution that pianists can use, and that makes use of kinesthetic cues, is to play the passage somewhat differently each time around (e.g., faster or more slowly, or with a different interpretation). This often makes musical sense anyhow. The kinesthetic cues will then be somewhat different at the end of each repetition, with the result that cue generalization is reduced.

Practicing "Getting Stuck"

Many performers unwittingly practice "getting stuck." They do this when they practice a passage by repeating it a number of times. The problem is created when they play until they reach a certain point in the passage, and then go back to the beginning of the passage. They may not realize that if they break off at the same point every time and go back to the beginning of the passage, they are, in effect, practicing that cycle. The compound cue that prevails at the breaking-off point becomes established as the triggering cue for the starting--over routine as well as for the desired continuation of the piece.[13] Thus, a branching point or fork is built into the chain, with the result that tenseness builds up just before that point in the piece is reached.

One way to avoid that problem is not to break off at the same point every time. The breaking-off points should be spread over one or two measures. That way, no single compound cue is immediately followed by the restart routine too many times. Because the damage is then diffused and spread out, the tendency to break off at any particular point will be relatively smaller.

In my experience, serious damage is caused only if any compound cue is followed by the restart routine more than two or three times. It is common for inexperienced pianists (and even some experienced ones) to break off at the same point and restart the routine twenty or more times, in which case future derailments or problems of tenseness become very likely.

PERFORMANCE MONITORING IN PRACTICING

Philogenetic Origins of Short-Term Memory

The nervous system has a short term memory mechanism for storing visual or auditory information for a few seconds, and other, more complex mechanisms for long-term memory, where information is stored for much longer times ({P} Kosslyn, 1980; {Rev} Schmidt, 1988, pp. 503-508; {P} Baddeley, 1995; {P} Sqiure & Knowlton, 1995). It is likely that the short-term memory mechanism exists in all animals that depend on guided locomotion through the environment. Guided locomotion requires a continuing flow of sensory (e.g., visual) cues regarding the space about to be traversed.

> When we run over rough terrain, we look a few yards ahead, a distance that will take about one or two seconds to traverse. That look provides us with the visual cues that will trigger the appropriate motor programs for placing our steps as we traverse that stretch.

> We need to retain the imaginal program for those cues only for the few seconds needed for those steps. Even before we have completely traversed that stretch, we are already looking at the next few yards, replacing the currently stored short-term memory imaginal program with the new one. The cycle keeps repeating as we run ({P} Thomson, 1983).

Short-Term Memory and "Following"

It is obvious that the same process occurs in performances like walking, crawling, swimming, flying, driving a car, or riding a bicycle. It is less obvious, but very likely, that the same or a similar process is also the basis for reading, listening, taking dictation, simultaneous translation, and many other seemingly diverse activities.

> When reading, we store each visual image of each string of printed characters in short-term memory only for the split seconds it takes us to visually decode them. We encode those visual stimuli into words and syntactic structures, and then retrieve the concepts with which these are associated resulting in what we call "comprehension." Even before we have completely finished that process for that string of characters, we are already looking at the next string of characters, substituting their visual image in short-term memory for the previous one. The cycle keeps repeating as we read along, and takes about two seconds per eight words for a good reader ({E} Buswell, 1920). Each new cycle begins while the later stages of the previous one are still in progress.

There is an obvious parallel between the reading and locomotion processes. The same basic process also occurs in wide variety of performance tasks. We will call it "Following," with the capital F indicating that the term is a defined technical term. It is possible that our generalized Following ability is the result of our nervous system having evolved to accommodate the requirements of locomotion. The process of locomotion is of such universal importance in the animal kingdom that it would be surprising if the structure of the nervous system had not evolved in a way that makes this process as efficient as possible.

If we close our eyes, open them for a split second, and then close them again, most of us have the experience of a clear and detailed after-image that lasts from about half a second to two seconds.[14] That ability may be closely related to short-term memory and to the brief retention of cues during Following.

Monitoring in Following

All types of Following present the follower with a continuous stream of cues. Responding selectively to certain types of cues, sometimes called "attention" ({P} Guthrie, 1959, p. 187; {Rev} Shiffrin, 1988), is the result of the learning history and of the behavioral contingencies that are in effect at the time. Neurological studies have shown that attention functions like a spotlight. When a monkey has learned that an important visual stimulus normally appears in a certain area of his visual field, the corresponding area of the visual tract will be "primed," in that the neurons in that area of the visual tract will be at a higher level of excitation than other areas of the tract ({E} Duncan, 1984; {Rev} Johnson and Dark, 1986). Another mechanism of attention may be the recruitment of fast-access resources so that potential interfering behavior is minimized.

The programs used in discriminating cues during Following are variously called "scanning," "monitoring," "set," "readiness" ({P} Woodworth & Schlossberg, 1955, p. 830), and "vigilance" ({E} Holland, 1958).[15] We will simply call it "monitoring." The behavior of monitoring is itself subject to shaping, like any other program, and can become selective for certain types of cues ("selective attention" and "set") ({Rev} Shiffrin, 1988; {Rev} Naatanen, 1985). When we discriminate a cue during Following, that cue can trigger a series of programs that can result in overt action or entry of the image into longer-term storage thereby causing it to be remembered.[4]

Following in Performance Learning

There has been a substantial amount of performance research where the independent variable was "knowledge of results." Monitoring provides continuous and immediate knowledge of results.

It has been shown that knowledge of results is most important during the early stages of learning a performance, and less important later (Newell, 1974) when all it does is help avert deterioration of the performance. Monitoring too is most important during the early stages of learning a performance.

In musical performance learning, Following is important in two types of situations. One is sight-reading from a musical score. The other is monitoring one's own performance during practicing, in an objective and detached way, as if the performance were by someone else.

> Pianists can monitor their own performance while practicing ({P} Hoffmann, 1909/1976, pp.48-49; {P} Slenczynska, 1961; {P} Gieseking and Leimer, 1972). Examples of significant cues are slurred notes, inaccurate rhythms, or other faults ({P} Gruson, 1988; {P} Miklaszewski, 1989).

As a pianist repeatedly matches the observed performance against the internal model, and self-administers reinforcements according to the goodness-of-match, the performance gradually improves as the parameter settings of the routines shift in the desired direction. A coach's may advise the pianist to monitor with selective attention for certain particular categories of uneconomical and invalid movements and coordinations. Good performance teachers stress the importance of concentration, attentive listening, avoidance of

[4] There are, of course, many techniques for remembering and ways to remember.

fatigue, and alert monitoring while practicing ({P} Sandor, 1981, p. 189; {P} Gerig, 1974, p. 165). Good teachers and coaches also provide special discrimination training to the learner regarding the important cues to watch for during monitoring.

Following in Sight Reading

In some of the more complex types of Following, like reading for comprehension, taking dictation, receiving Morse code, simultaneous translation, and sight-reading music, each cycle of Following consists of several stages, which are staggered, in that each new cycle begins while the previous one is still going to completion.

> In taking Morse code, for example, the receiver first lets a certain number of characters and words accumulate, usually until they "make sense," i.e., become chunkable, and only then writing them down. Fred S. Keller called that phenomenon "copying behind" ({P} Keller & Schoenfeld, 1948). Donald A. Cook showed that the distances by which subjects copy behind depend on the sizes of the units they are able to store, which in turn depends on the sizes of the chunks and concepts in their repertoire, and the "chunkability" of the cue stream ({E} Cook, 1972). Cook has also pointed out that reading outloud requires the reader to be looking a certain distance ahead of the words he is articulating.
>
> Simultaneous translation is an example of multi-stage Following whose cycles involve an additional step. Each cycle's staggered levels include listening, comprehending, translating, and speaking.

Musical sight reading clearly involves multi-stage Following. With each "look," the reader tries to take in as much of the score as necessary to "make sense of it," i.e., to match it up with any of his existing musical and motor routines and concepts. Those musical and motor routines are then executed while the next stretch of the score is already being looked at and visually decoded. So, the basic cycle of steps in sight reading consists of (a) visually decoding a certain stretch of the score, (b) retrieving or assembling the corresponding musical concept, and (c) playing the notes corresponding to that concept.

Subsequent Passes Through the Score

The second, third, and subsequent readings through the same score are no longer "sight reading." Initial sight reading from the music score obviously involves Following, but subsequent readings do not. Musicians tend to call the initial readings "sight reading," and subsequent readings "looking at the score," implying, correctly, that a different process is at work.

In successive readings, the visual cues from the score gradually become less "informational." After several playings-through of the same score, the non-visual musical concepts progressively form themselves into chains, with each successive musical concept triggering the next one with increasing strength, due to repetition. Also, the kinesthetic cues from the preceding routines acquire increasing triggering power. But the kinesthetic cues do not emanate from finger movements only. They also emanate from the eye movements involved in looking at the score. Those eye movements tend to become and remain part of the motor programs that are created, and the resulting visual cues from the score become integrated into the compound cues that trigger each successive playing routine. As learning progresses, what forms is a fused chain of performance routines held together by compound cues that include visual cues from the score and auditory and kinesthetic cues from the motor routines. The visual cues from the score, though they remain active in cuing the motor routines, are no longer "informationally" related to the notes being played. In fact, if one examines exactly where on the score the performer is looking in relation to the music being played, one will often find that a gradual drift has occurred, with the performer looking at the notes just played rather than those about to be played. So, even when such visual cues are no longer providing any information as to what notes to play next, their cuing function can still be important in triggering the performance routines, and the performer can be totally dependent on those non-informational visual cues from the score.

"Memorization" is said to have occurred when the visual components of those compound cues are no longer needed, so that looking at the score is unneces-sary.[16]

Looking at the Score in Practicing

In connection with performance learning and practicing, it is important to understand that since the sight-reader's eyes and attention are fixed on the printed score, they are unavailable for attentive performance monitoring. To make them available for that function, and eliminate the need for the visual cues provided by the score, two strategies can be used. One is far more desirable than the other for reasons that will now be explained.

The learner's task in practicing is to shape the performance, as efficiently as possible, by Following it, with attentive and aware monitoring.

> For pianists, that requires keeping the eyes on the fingers to ensure economical and valid movements. If the initial executions of the performance are "readings" of the music, the attention is divided between looking at the score, looking at the fingers and keys, and listening attentively. Looking at the fingers and attentive listening comprise Following, and are essential for attentive performance monitoring, as was explained earlier, but attending to visual cues from the score interferes with attentive monitoring. When attention is thus divided, it is inevitable that various mistakes and invalid routines will become encoded in the performance's programs.

Divided attention is not as effective as undivided attention for monitoring the performance ({E} Brown, McDonald, Brown, & Carr, 1988). When the eyes are on the score, monitoring is necessarily degraded, and the performance shaping process is correspondingly impeded. It only takes a few repetitions of invalid routines and other mistakes for these to become registered. And yet, that is how most musical performers learn new material, by reading and playing through it a number of times.

In that process, once dependency on visual cues has been eliminated, full attention can be focussed on the performance cues, and the process of Following and monitoring can begin in earnest. But by this time, its main function must be correctional —to undo or overwrite the mistakes and invalid routines that have become established, a process that is highly inefficient at best, and unsuccessful at worst. A performance that has been corrected or "cleaned up" always remains vulnerable to resurgence of the "mistakes" during the real performance.

The Efficient Way

The guiding principle is "Always monitor alertly when practicing." Sight-reading a passage when first learning to play it violates that principle. But how can one practice a new passage without first sight reading it?

The great pedagogues of the past recommend first reading it covertly, without trying to play it while reading it ({P} Gieseking & Leimer, 1972; {P} Kentner, 1976, p.88; {P} Hoffmann, 1909/1976, p. 114). This does not require the spectacular feats of memorizing an entire score of many pages by merely reading it through covertly, a feat of which highly competent musicians are capable. Most learners are able to memorize the score a few notes or a measure at a time, so that when they play those notes for the first time, they can carefully plan each movement, routine, and position shift, with their eyes on the hand rather than on the score, and monitor the execution closely with fully attentive monitoring.

> Practicing the part of each hand separately and slowly, especially during the initial practice runs, is important for the same reason: It permits full attention to be focussed on each individual finger and hand movement, with alert monitoring, so that valid movements are programmed and invalid ones avoided, right from the start.

One reason why few pianists and piano teachers have discovered how very beneficial it is to practice in this careful way at the start of learning a new passage is that the benefits are highly delayed. They are not evident during the early stages of practicing the new passage. They manifest themselves only later, in terms of the speed with which the final desired performance is achieved, and the ultimate perfection and stability of that performance.

MANAGING THE PRACTICING PROCESS

Length of Practice Sessions

Attentive and alert monitoring of the performance during practice is difficult to sustain for long periods of time, and suffers when the student is tired. In addition, fatigue tends to result in the execution and practice of invalid routines, as we discussed earlier.

These are the reasons why the pedagogical literatures of most performance disclipines advocate practicing only when well rested, alert, and able to concentrate, and never when tired or burned out ({P} Auer, 1921; {Rev} Ericsson, Krampe, & Tesch-Romer, 1993).

Experimental studies have shown that practice sessions of about one hour per day are optimal for beginners in most performance disciplines, and that the point of diminishing returns for more expert performers occurs at about four hours, with benefits starting to diminish after two hours ({P} Welford, 1968; {P} Woodworth & Schlosberg, 1955). Many music pedagogues have recommended one hour as the most efficient length of a practice session, with ample rest between sessions ({P} Auer, 1921; {P} Seashore, 1938/1967).

The Need for Performance Refreshment

Practicing is not only for the original learning of a performance. It is also necessary for refreshing or restoring a previously learned performance. One of the reasons why performances deteriorate as a function of successive repetitions, and need periodic restoration, has to do with monitoring. Performing differs from practicing in that when performing, effective monitoring is difficult or impossible. The special demands and stresses of performing greatly reduce corrective feedback. When performing, attention must be focussed on the musical interpretation.

Another reason performing degrades the performance is that one can never execute even an extremely well-learned routine exactly the same way twice in a row.

> A convincing demonstration of that fact is provided by writing one's signature (a well--established and highly practiced routine) ten times in a row in the same place. The superimposed signatures become increasingly fuzzy.

Since programs are written by virtue of being executed, we can assume that the program too becomes somewhat fuzzier each time it is run. The inevitable result of executing a program repeatedly without restorative practice is gradual degradation.

The performance's original sharpness can be restored by periodic refreshment ({P} Keele, 1982, p. 169). Professional performers, knowing that their performance becomes progressively degraded with each execution, periodically reprogram the performance by means of practice with monitoring and the types of practice techniques discussed in the previous sections. Refreshment practice can also focus much more time and pinpointed attention on specific weaknesses or imperfections, than can actual performance ({P} Williams, 1988).

Scheduling Practice Sessions

It is useful to remember that spaced learning and practice sessions are more effective than "massed" ones ({E} Hovland, 1951). In physical tasks, some of that effect may be the result of physical fatigue and the benefits of resting the muscles. But rest by itself does not explain the benefits of spaced learning in non-physical tasks ({P} Stelmach, 1969; {P} Dunham, 1976). It is likely that the intervals between trials or sessions provide time not only for muscular rest, but also for "neural housekeeping" functions, like restructuring and reorganizing the newly learned programs, thereby making them more efficient and accessible. Several studies suggest that for many types of performance, the largest amount of learning is achieved when only 20% to 40% of the session is devoted to "practice" and the rest to interspersed periods of other activities ({P} Graw, 1968; {P} Schmidt, 1988, pp. 384-391).

However, the finding that massed practice is less effective than distributed practice may not be completely general, and depends on the type of performance involved. The reason for this may be that the benefits of restructuring and resequencing depend on the type of task or performance.

Also relevant here is the body of data from research on sleep and dreaming. Sleep and sleep deprivation can differentially affect various types of performance. It is possible that one function of sleep and dreaming may be to "clear out" the contents of the fastest-access facility and restore its availability ({P}

Crick and Mitchison, 1983).

Awareness in Performance Learning

The type of routine most people refer to as "awareness" ({P} Skinner, 1953; 1957, p. 314; {P} Hineline, 1989) might consist of a verbalization, overt or covert, of the type "I just did (or saw, or heard, or felt) X." The semantic basis for the term awareness may also extend beyond mere verbalization, but in the context of performance learning, we are interested primarily in verbal awareness.

One can be "aware" of any routine regardless of whether it is overt or covert, although one is more often aware of overt routines than of covert ones. Fortunately, we are unaware of the vast preponderance of our routines, both overt and covert, and of changes that occur in those routines as a result of learning ({P} Hefferline, Keenan, & Harford, 1959). But we can learn to become aware of any particular routine.

> Some yoga exercises are designed to make people aware of muscle activity of which they are normally unaware. Awareness of an activity can help establish control over it.

When a program needs to be modified, first making the subject aware of it is often a useful technique ({P} Langer, 1989). The coach's or therapist's challenge is to discover programs requiring modification and then make them overt. They are made overt by bringing about their verbalization by the subject. Performance teachers, coaches, and therapists often try to make the subject verbally aware of certain undesirable routines, as a step toward giving the subject some control over them ({P} Perls, Hefferline, & Goodman, 1951). Feedback via videotapes too can be particularly useful for increasing awareness, especially when used in conjunction with feedback from an expert coach ({P} Carre, 1972). A teacher, coach, or therapist may tag an awareness program onto any routine by statements like "Listen to (or look at) what you just said (or did)," or "Let me show you what you just did."

Here is the mechanism by which these technique can modify a performance: An overt routine is often immediately preceded by a covert version of the same routine. This covert version can be an anticipatory or preparatory imaging of the routine (as discussed in the Section entitled "Covert Routines in Overt Performance"). When this covert anticipation is tagged with an awareness routine, the overt execution that follows can be altered in the desired way or even aborted.

Advantages of Total Immersion

"Total immersion" is advantageous for performance learning.

> A new language is learned most efficiently if that language is the only one spoken (as in the Berlitz method)[17]; It is common for serious performers to devote eight or more hours per day to their art ({P} Hoffmann, 1909/1976, pp. 46-47); And the various "human potential" workshops are often offered as sixteen-hour-per-day weekends.

Total immersion is effective because only a limited number of programs can be made available for very fast access ({P} Friedman, Polson, & Dafoe, 1988; {P} Brown, McDonald, Brown, & Carr, 1988). Total immersion makes more of the brain's limited fastest-access resources available for the learning task at hand. New programs can be assembled more efficiently if all of the required neural resources, along with the fragments and components from which they are being assembled, are all instantly accessible, and if the needed managerial programs are devoted exclusively to the performance in question. "Divided attention" is maintained at the expense of each of the activities among which the available attentional resources are divided ({E} Brown, McDonald, Brown, & Carr, 1988). Also, when tasks are performed concurrently, the quality of monitoring of each task is degraded ({E} Brown, McDonald, Brown, & Carr, 1988).

There are many open questions as to the degree to which "processing resources" can be shared. For example, it has been found that each hemisphere controls its own set of processing resources that it cannot share with the other hemisphere ({P} Friedman, Polson, Dafoe, 1988). The reason why fast access resources are limited may be that only limited portions of the CNS can be maintained at a high level of priming at any given time. The programs in fast access memory are those that are needed for the most urgent tasks.

Thus, the value of total immersion is not due to the total amount of time spent on the activity; rather, it is due to the exclusion of other activities that would compete for the fastest-access and attentional resources.

Competing Drives

A potential source of competition for the fastest-access resources is hunger, thirst, pain, physical discomfort, anxiety, worry, preoccupation with problems, and yes, romantic love. When such emotional states pre-empt fastest-access resources, they interfere with performance and retard performance learning.[18] Because of their biological urgency, one would expect such emotion programs to have first call on the fastest-access resources. They would normally pre-empt those resources for such survival-related functions as fight-flight, sex, or other biological functions that require the rapid mobilization of effector resources.

The significance of this is that learning and practicing performance skills is most efficient when basic drives and motivations are quiescent.

The Teacher's Functions

Management of the learning and practicing process is best viewed as a shared responsibility of the student and the teacher. Both need to understand the principles of learning and practicing skilled performance.

On the basis of the present analysis, the teacher's or coach's over-arching functions are these:

1. Shaping the learner's internalized model of the desired performance.
2. Building and shaping valid coordinative structures.
3. Teaching all necessary routines, including the covert ones.
4. Teaching the student to apply the principles of performance learning
5. Motivating the student by teaching appropriate "results" routines.

All of the other functions discussed in this book are subsidiary to these.

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[1.] The author is a pianist who has used and tested his "how-to" manual on this performance technology's application to the learning and practicing of piano performance since 1980.

[2.]In the motor program literature, the term "motor program" is used for both the CNS encoding and for the behavior that occurs when the program is run. Given our present objectives, however, the distinction is vital, and the new term "routine" is accordingly introduced. We are using the term "routine" rather than the more widely used psychological term "response," which connotes a brief all-or-none observed event that meets a certain criterion or produces a specified environmental effect. That connotation is too restrictive for our needs, since in performance learning, both the criterion and the meeting of it are in flux during the performance shaping process.

[3.] Examples of covert behavior in chess playing are verbalizations and algorithms of the type "How does the balance of material stand?", "Which side has the advantage?", "What move would my opponent make if it were his move again, prior to my making my move?", "What is the most serious weakness in the opponent's position, and in my position?", "What positioning or configuration of pieces do I want to achieve?", "Given features X, Y, and Z of the position, what is the best strategy?" The covert asking and answering of such questions is what the chess player must learn. In the game of go, some of covert questions and answers include "How much territory does each side control?", "Which groups are alive and which are dead?", "Which groups are the weakest and most vulnerable to attack?", "Where is the group's vital point?", "Must a given move be answered?", and "What is the biggest move on the board?"

[4.] We are using the term "cue" for the initiating event, rather than the term "stimulus" which is widely used in psychology, or the term "motor command" often used in the field of motor behavior. We want to avoid the baggage of connotations that these terms carry. For instance, many psychologists, especially in the field of psychophysics, often define "stimulus" as an event that is observable or measurable independently of its behavioral effects, and specify it in terms of the experimenter's manipulations of the subject's environment. By that definition, not every stimulus is a cue, as when the stimulus is below the subject's perceptual threshold. The term cue, as used here, is defined only in terms of its behavioral effects, and is a construct, like the concepts "proprioceptive stimulus" or "response-produced cue" which are widely used in psychology.

[5.]The term commonly used in the cognitive neuroscience, and motor behavior literatures, is "representation." Since that term has connotations that could be misleading for some of the ways we will be using it, we have adopted the more general term "imaginal program."

[6.]Briefly, A, B, and C form an "equivalence class" if the subject has learned that A and B are related in a certain way, and that B and C are related in that same way. The subject will then sometimes behave in accordance with A having that relationship with (being "equivalent" to) C, without ever having explicitly been taught that last relationship. This phenomenon can, in principle, be extended over any number of stages, and for various types of relationships like "is a", "is like" "equals", "is greater than", "is an example of", "is in", etc.

[7.]Presumably because of differentials in theirrepertory of concepts and their use of conceptual "chunks," chess players' ability to remember chess positions from actual games is sharply correlated with their playing strength, while their ability to remember chess positions in which the pieces are placed randomly is independent of playing strength (De Groot, 19??).

[8.] Turvey et al. describe that process in the following quotation: "When you are just beginning to learn a skill, one of the first things you will notice is that you eliminate, as it were, some of your degrees of freedom - put simply, you keep a good part of your body fairly rigid. You do not exhibit the flexibility of a skilled performer. Watch a child learning how to hit a baseball. Initially he or she stands quite rigid, facing the ball, holding most of the body stiff. This posture simplifies the problem, but it does not allow a very efficient swing. As the child gets slightly better, one of the things he or she will do is allow shoulder movements into the swing. Several degrees of freedom are "unfrozen". Nevertheless, there is still a ban on many degrees of freedom because they constitute so much trouble for the child... Why is the batter attempting to regulate more degrees of freedom? Fundamentally, the skill demands it. A good baseball batter must allow flexibility of the hips, shoulders, and wrists. The additional degrees of freedom are very important in giving power to the swing."

9. Here is how Tuller et al. describe the application of this principle in marksmanship: "The first thing we can observe about a skilled marksperson is that in comparison with the amateur the oscillatory movement is less... While aiming the gun, any change in the wrist or shoulder joint will cause the gun to deviate from target. In the unskilled marksperson, movement at one joint is not compensated by a change at the other joint, thus throwing the gun off target. The joints are relatively independent of each other. But in a skilled marksperson ... the two joints are constrained to act as a unit such that any horizontal oscillation in the wrist will be matched by an equal and opposite horizontal oscillation in the shoulder ({P} Arutyunyan et al., 1969). It appears that the joints relate among themselves according to some equation of constraint... The difference, then, is that the skilled performer has found a way of constraining his or her muscles to behave as a single unit, that is, as a coordinative structure. And we may suppose that, in part, learning any skill entails a similar discovery of relevant constraints over the muscles used in the skill.... In the discovery of such constraints, effective control of the musculature is achieved through the reduction in the number of degrees of freedom that must be controlled independently."

10. In the clinical area, obsessive thought patterns, which, in their overt manifestations, can take the form of compulsive behavior routines, may often owe their strength, and perhaps even their origins, to superstitious conditioning.

11. Note that this is a description of what pianists normally do, not a recommendation for what they <u>should</u> do.

12. All <u>da capo</u> passages have that characteristic. The first time around, they repeat; the second time around, they continue. The problem also arises in classical impromptus, which follow the A-B-A-coda form, and in rondos, in which the same passages continue to recur.

13. The reason for the phenomenon of stuttering is related to that mechanism. In stuttering, the verbal motor program keeps recycling to the beginning instead of continuing. As Goldiamond has shown, a practical strategy for eliminating stuttering is to establish a new motor program for the verbal chains involved and abandon the defective one ({P} Goldiamond, 1962).

14. The one-to-two second range is fairly usual. The actual length of that time interval appears to differ widely from person to person, from situation to situation, and from time to time for the same person. For people with eidetic imagery, it lasts much longer.

15. These are present as innate processes in all animals, at least at some level. For example, every duckling scans the sky above for the silhouette of a hawk, and for nothing else. The duckling will not notice a pigeon flying above. We could say that the duckling is always attentive and vigilant for the hawk silhouette. In a similar sense, most animals are attentive to movement in their field of vision. Flower-seeking insects are attentive to bright colors, and, during the mating season, to certain chemicals called pheromones.

16. The expression "performing from memory" is normally used in the sense of "performing without sight of the score," and the term "memorization" is used to mean "eliminating dependency on the score." When the musical score provides an important source of visual cues for the performer, it is often said that the performance is not "from memory." Actually, with the exception of initial sight reading, every performance, like all behavior, depends on memory.

17. When bi- or poly-lingual people haven't spoken a language for some time, retrieving a particular word or phrase in that language may be difficult, while that same word or phrase can be retrieved instantly without searching when they resume speaking that language. This observation suggests that speaking the language continuously for a short time creates fast access to all of the other programs for speaking that language.

18. This principle evidently has far-reaching implications for education in general, educational practices, and early childhood development theory.