

CHAPTER 3

THE MOTOR SYSTEMS APPROACH TO MOTOR LEARNING WITH SPECIAL REFERENCE TO PIANO TECHNIQUE

3.1 Introduction

While motor learning research has been in progress for over a century, Schmidt (1988b:15-16) states that the late 1970's and early 1980's are characterized by a decline in interest in the field of motor learning. This decline can be attributed to an increase in interest in motor control and the information-processing approaches associated with motor control; "[t]his is unfortunate because the issues involved in learning have perhaps the most practical applicability to training ... and teaching in general" (Schmidt 1988b:16). Nevertheless, two of the three¹ fundamental theoretical models for learning - which "... may have great relevance to our problems in music education" (Sidnell 1986:8) have gained particular prominence around these dates, namely the closed-loop theory of Adams and schema theory as formulated by Schmidt².

At this stage it is appropriate to note that all theories of learning essentially attempt to explain a certain generalizable finding, termed the *law of practice*, which states that "... the log of the performance tends to change linearly with the log of practice" (Schmidt 1988b:491). This logarithmic relationship between practice and performance can be explained as follows (Schmidt 1988b:460):

... the rate of improvement at any point in practice tends to be linearly related to the "amount left to improve" in the task. So, early in practice, when there is much learning left to accomplish, the speed of improvement is very rapid as compared to the end of practice when there is not so much "room for improvement" remaining.

In the following sections the fundamental concepts of motor skill, motor learning and transfer of

¹Motor programming, which is considered by some, for example Sidnell (1986:8) to be a third theory of learning, has been discussed in Section 2.8.

²The notion of motor schema is not new, however.

learning will be examined more closely.

3.1.1 The concept of motor skill

3.1.1.1 Definition of motor skill

While Kerr (1982:310) describes a motor skill as "any muscular activity that is directed to a specific objective"³, the definition by Guthrie (1952) can possibly be regarded as the best of its kind (Schmidt 1988b:3): "[s]kill consists in the ability to bring about some end result with maximum certainty and minimum outlay of energy, or of time and energy".

Contrary to what the previous definitions may suggest, the description and identification of skilled motor behaviour is not necessarily a simple or clear-cut matter. This is due to the wide range of behaviours that can be regarded as skilled, the fact that skilled behaviour is evaluated according to its level of competence or proficiency, and the fact that not solely motor processes are involved in the execution of motor skills. These points are illuminated in an extended definition of the more general term *skill* by Adams (1987:42):

1. Skill is a wide behavioral domain. From the beginning, skill has meant a wide variety of behaviors to analysts, and the behaviors have almost always been complex.
2. Skill is learned. That skills can lack proficiency, and acquire it gradually, with training, conflicts with the dictionary definition of skill, popular usage, and how a number of investigators have used the term. A dictionary and a layman will define skill as the ability to do something well, and psychologists have often said the same thing... No investigator, however, should have more than a passing interest in behavior at its asymptote; a scientific understanding of skill must be concerned with all grades of it.
3. Goal attainment is importantly dependent on motor behavior. Any behavior that has been called skilled involves combinations of cognitive, perceptual and motor processes with different weights. Mathematicians have cognition heavily weighted in the description of their behavior, with virtually no weight for perception or the motor response with which they write the answer to a problem. On the other hand, the behavior of tennis players could not be meaningfully described without including the motor responses stemming from their perceptual evaluation of the situation and the cognition in their decision making.

In view of the above, it should be pointed out that the term skill, as used in the present study, implies motor skill; skilled performance therefore is predominantly muscular⁴.

In his discussion on motor skills, Kerr (1982:18) notes that when the muscles are tired, the

³All muscular activity not consciously directed toward some objective, such as all reflex activity and muscular twitches, is excluded from the definition of motor skill (Kerr 1982:5).

⁴Thus, as is usually found in motor behaviour science, the cognitive processes involved in skilled motor behaviour are not emphasized *per se* in the present study.

performance⁵ may deteriorate, but the skill is not lost. It is, however, of some significance to note that in the bulk of the literature on piano technique, the view is held that the "building in" of measures to prevent the muscles from getting tired - at least to a degree where the quality of the performance is not influenced - is implicitly part of the process of attaining technical skill. The pianist Alek Peskanov (Elder 1986:12), for instance, recalls his teacher indicating to him that he would never get tired provided he employed the "correct" physical strategy - "... I don't get tired because she showed me so many positions of the hand."

3.1.1.2 Classification of motor skills

In order to organize the field of psychomotor⁶ learning, which encompasses an infinity of motor skills of varying degrees of difficulty, the concept of taxonomies were introduced. The term *taxonomy* refers to "... an orderly classification according to presumed natural relationships" (Kerr 1982:9). Several benefits are attached to the concept of taxonomies. By identifying and describing the common elements between motor skills, understanding of these skills is enhanced. Directing research efforts at the common elements between motor skills makes the research findings more generally applicable. Also, the effect of a particular teaching technique on different motor skills belonging to the same category can be studied (Kerr 1982:9-10). It is of some importance to note in the context of the present study, Reed's (1988:46) pointing out of the fact that, up to the present, all taxonomies of human skill adhere to the assumption that all skills are built up out of "... elementary neurobehavioral units".

While it is not of particular interest for the purposes of the present study to discuss the classification *per se* of the vast amount of different types of motor skills, insight can nevertheless be gained into the classification procedures by considering the three main categories of motor skills as proposed by Kerr (1982:6):

1. The *phylogenetic skills*, or the skills common to all humans that are developed in early life and that are dependent on maturation. Examples are walking and talking.
2. The *communication skills*, which are essential for educational development. Examples are writing and reading.
3. The *recreational skills*, or those skills "learned for oneself". Examples are painting and playing a musical instrument.

The last two categories are often referred to as the *ontogenic skills*, i.e., skills learned by and unique to an individual, requiring a conscious effort on his part.

⁵*Performance*, as opposed to motor *learning*, will be defined in Section 3.1.2.1.

⁶The significance of the prefix *psycho* will be explained in Section 3.1.2.1.

3.1.2 The concept of motor learning

3.1.2.1 Definition of motor learning

Kerr (1982:6) defines *motor learning*⁷ as "... a relatively permanent change in the performance of a motor skill resulting from practice or past experience", where *performance* can be defined as (Kerr 1982:5) "... a temporary occurrence fluctuating from time to time: something which is transitory". For Kerr, experience includes not only actual execution of the motor skill by oneself, but also the observation of others performing, for example watching the teacher perform.

Establishing a shift in emphasis away from outward behaviour of the learner, Schmidt (1988b:346) describes motor learning as a collection of internal processes⁸; the nature of these internal processes is "... what learning theorists try to understand". In particular, motor learning is (Schmidt 1988b:375) "[a] set of internal processes associated with practice or experience leading to relatively permanent changes in the capability for skill".

For purposes of further elucidation, Schmidt's (1988b:345-346) explicit identification of the four distinct characteristics of motor learning implied in the definition above is reproduced here:

First, learning is a *process* of acquiring the *capability* for producing skilled actions. That is, learning is the set of underlying events, occurrences, or changes that happen when practice enables people to become skilled at some task. Second, learning occurs as a direct result of practice or experience. Third, learning cannot (at our current level of knowledge) be observed directly, as the processes leading to changes in behavior are internal and are usually not available for direct examination ... Fourth, learning is assumed to produce relatively permanent changes in the *capability* for skilled behavior; changes in behavior caused by easily reversible alterations in mood, motivation, or internal states (e.g., thirst) will not be thought of as due to learning.

The internal capability for responding is termed *habit* by Schmidt (1988b:346) following the designation by James of 1890. Defining learning as a capability for skilful action implies that, once the capability for responding is established, the skill may either be executed - when the external conditions are favourable, or refrain from being executed if, for example, fatigue is present or motivation is low. Thus, the definition of Schmidt clearly provides for the important distinction between learning and performance pointed out earlier; "... behavior may vary for a number of reasons, only some of which are a result of a change in the internal capability for responding

⁷Motor learning can also be considered a field of study; in this case "[a]n area of study focusing on the acquisition of skilled movements as a result of practice" (Schmidt 1988b:17).

⁸A *process* is "... a set of events or occurrences that, taken together, lead to some particular product, state, or change" (Schmidt 1988b:346).

produced by practice" (Schmidt 1988b:347).

Not classified under the heading of motor learning, are all changes in the capability for responding not acquired through practice; these typically include changes due to maturation and aging and temporary changes in the physiological state of the learner, such as fitness level (Schmidt 1988b:347).

Finally, on consideration of the perspectives from which the present study is conducted, the important distinction between the concepts of *motor learning* and *psychomotor learning* should be pointed out. The prefix *psycho* in the latter signifies, according to Kerr (1982:6), "... a large central control operation that not only supervises the specific muscle commands regarding *how* to move but also supervises the decisions of *why, when, where, and how far* to move". Because action theorists reject the idea of central control, the more general term *motor learning* is therefore used in this thesis.

3.1.2.2 Transfer of motor learning

Schmidt (1988b:371) defines *transfer of learning* as "... the gain (or loss) in the capability for responding in one task as a result of practice or experience on some other task".

To illustrate the transfer concept, the question might be asked if, for instance, practising the harpsichord would produce benefits or losses - or neither - for a task like piano playing. If it appears as if piano performance is more skilful after practising the harpsichord than it would have been under no beforehand experience of the harpsichord, it is likely that *positive* transfer has occurred of the harpsichord skills to playing the piano. If, on the other hand, the learner's performance at the piano is worse after practising the harpsichord than it would have been if the learner did not practice the harpsichord at all, then *negative* transfer of the harpsichord skills to the piano playing skills has occurred.⁹

3.2 Feedback and knowledge of results (KR)

The information that a performer receives about his performance while attempting to learn a skill, is termed feedback. Feedback, which can take many forms in the environment or laboratory, can also be regarded as (Schmidt 1988b:454) "... [s]ensory information that is contingent on having produced a movement". According to Schmidt (1988b:423), feedback information is, next to practice, the most

⁹The reader interested in this interchange involving the piano and harpsichord is referred to Martinez (1990) for more information.

important variable for motor learning:

Understanding the principles of how such performance information "works" will provide additional bases for the decisions about the design of teaching or training environments.

It is possible to divide *response-produced feedback*, i.e. information produced during or after the movement, into two broad sub-classes, namely

- intrinsic feedback
- extrinsic feedback

These two classes will now be considered in greater detail below. Of course, the underlying assumption will be that motor learning occurs in a closed-loop situation where the task is repeated until it has been mastered. During and after each trial, feedback information is used to improve the next trial, and so on, until the task is mastered after enough trials have been performed.

3.2.1 Intrinsic feedback

Intrinsic feedback is "[t]hat feedback normally received in the conduct of a particular task" (Schmidt 1988b:454), being a direct consequence of the movement (Kerr 1982:309). Intrinsic feedback is picked up through various sensory channels, for instance the aural, visual and tactile facilities of the pianist. Closely associated with intrinsic feedback is the concept of *subjective reinforcement*¹⁰, "... the subject's self-generated error signal, based on comparing feedback against a reference of correctness" (Schmidt 1988b:455). Not every performer uses intrinsic feedback to the full; it may be necessary for the pianist to be taught how to exploit useful aspects of intrinsic feedback. Thus the student could typically be taught to make sure, through awareness of physical sensations, that the thumb in scale playing remains free of unnecessary tension, for example.

In subsequent sections three types of intrinsic feedback that are relevant to the pianist will be discussed. These types of feedback are *aural feedback*, *kinesthetic feedback* and *visual feedback*, aural and kinesthetic feedback probably being the predominant types of feedback in piano playing.

3.2.1.1 Aural feedback

The use of aural feedback consists thereof that the pianist will constantly be listening to aesthetic aspects of his performance, like tone quality, phrasing and timing, bringing about appropriate changes in motor responses where required.

¹⁰This topic will be explained more fully in Section 3.4.1.2.

According to Giesecking (Giesecking & Leimer 1972:5), the critical "self-hearing" associated with aural feedback is "by far the most important factor in all of music study". As Lhevinne (1972:11) notes, "[t]he finest students are those who have learned to listen". Giesecking points out that self-hearing is essential for a good technique, and that it can be developed through training¹¹:

Only trained ears are capable of noticing the fine inexactitudes and unevennesses, the eliminating of which is necessary to a perfect technique. Also, through a continuous self-hearing, the sense for tone beauty and for finest tone shadings can be trained to such a degree that the student will be enabled to play the piano with an irreproachable technique ...

Under Leimer's method, this training effort is focused on the detection of firstly tone quality, and secondly tone duration (Giesecking & Leimer 1972:20).

It is common knowledge that, because of numerous subtleties involved, the use of aural feedback is far from simple or straightforward. According to Giesecking and Leimer (1972:10), most pianists do not hear themselves correctly, in spite of the fact that they are quite proficient at spotting wrong notes: "[f]or the pianist the noticing of the exact tone pitch is ... only secondary when compared with the noticing of the exact tone quality, tone duration and tone strength". This view is endorsed by Reubart (1985:88), who states that many pianists tend not to listen to what they are playing "... not because they do not choose to, but because they do not realize that they are not". Instead, these pianists perceive only what they expect to hear. Prostakoff and Rosoff (Whiteside 1969:22), and Whiteside (1969:28) observe that a musician's ear can be "conditioned" by his practising habits. An example is the predominant involvement of a performer with those parts of his playing apparatus involved in the articulation of individual notes, resulting in an ear that listens "notewise" and neglect of the well-being of larger units, like phrases.

3.2.1.2 Kinesthetic feedback

Kerr (1982:309) describes *kinesthesia* as "... the awareness of body position and movement based on proprioceptive information"; according to Harrow (1972:58), kinesthesia is manifested by the physical sensation experienced by an actor during the execution of a motor response¹². For all practical purposes, kinesthesia is the same as *proprioception*, which was defined in Section 1.5.

Exhortations to become acutely aware of physical sensations, which is not necessarily a matter of large, easily detectable differences, are common in the literature on piano playing. Some representative examples will now be examined. Bridges (1985:28) notes that, while the words mostly

¹¹An idea which corresponds with Gibson's notion expressed in Section 4.2.8 that the perceptual systems can be trained to function more effectively.

¹²Discussion of the various receptors responsible for kinesthesia falls beyond the scope of the present study; Schmidt (1988b), however, devotes attention to this topic.

associated with Matthay's concept of technique are "weight" and "relaxation", the term "invisible technique"¹³ most aptly sums up its essence:

To him, technique was not just a matter of getting the visible motions right, but rather of properly coordinating the actions of the limbs by attending to the feelings associated with muscular contraction and relaxation.

According to Whiteside (Prostakoff & Rosoff 1969:22), the nature of the physical nuances involved in piano playing are such that they can only be felt, not seen or even heard. Giesecking and Leimer (1972:110) recommend in an explanation on the achievement of a so-called singing tone, that the fingers should be held straight rather than curved, allowing the keys to be depressed by the "... flat part of the first joint of the finger ... [i]n this manner the delicate sensory nerves of the fingers come into their own, making it possible for the player to bring forth a large scale of rich tone colors". Furthermore, instructions given by Neuhaus (1973:116-117) for practising trills rely heavily on the employment of kinesthetic feedback: the pianist should ensure active participation of the fingers only, practising the whole range of dynamics and speed. Sensory awareness can be enhanced by playing "... without at all raising the fingers over the keys so that not even a ... razor blade could be slipped between the fingertip and the key surface". Merrick (1958:52) describes procedures by which firmness of the hand combined with flexibility at the wrist can be made familiar in sensation. And Hoffman (1920:11) recommends that the division of labour between the limbs involved in the execution of tremolos can not be done consciously, but should rather be determined by the "right" feeling.

Reubart (1985:137-138), on the other hand, warns against a misplaced emphasis on the kinesthetic experience which is manifested in the myth that the player "... must be muscularly *tense* if he is to be musically *intense*". Such an emphasis could give rise to a detrimental kind of closed-loop system, in which both overly tense muscles and performance anxiety are role players: "... signals from the straining muscles form a feedback loop with the central and autonomic nervous systems to create and sustain performance anxiety that is often out of control". Reubart (1985:142) furthermore stresses that this problem is far from uncommon:

The feedback loop linking high muscular tension/high performance anxiety, musical intensity-muscular tension/high anxiety can be seen almost every day among some of our most talented student performers.¹⁴

¹³Compare the title of his monograph *The visible and invisible in pianoforte technique* (1947).

¹⁴One can only speculate on the extent to which statements like those of Slenczynska (1974:39) on the execution of the left-hand octaves in Chopin's *Polonaise* Op. 53 - "[y]ou will suffer physical pain and learn to endure it" - will cultivate the existence of such feedback loops.

3.2.1.3 Visual feedback

Visual feedback¹⁵ in piano performance is obtained through observation by the pianist himself of the motion patterns of his fingers, hands, wrists, elbows, arms and other members of the playing apparatus involved at any time; the approach to piano technique of Phelps (1981) for instance, relies heavily on the use of visual feedback. An indication of the nature that visual feedback information can assume in the playing of scales and arpeggios, is found in the relevant guidelines by Sandor (1981:70-71), some of which are reproduced below:

2. Each finger is to be helped by the rest of the playing apparatus, which assumes a corresponding position suitable to that particular finger.
3. The need for changing positions for each finger results in continuous adjusting movements of the arm.
4. In general, the wrist is at its lowest point when the thumb is used and at its highest point when the fifth finger is used.
5. Guideline 4 is modified when grouping of notes is involved; in groups the lowest wrist position is assumed at the beginning of the phrase, no matter which finger plays, and the highest position is assumed at the end of the phrase ...
6. When we play scales we should avoid placing the thumb under the palm; instead we should place it alongside the hand. A combined finger-wrist-arm motion prevents a cramped and uncomfortable position for the thumb.
7. Whenever the hand is in playing position, we should avoid an extreme pronation of the radius and ulna ... by slightly raising the upper arm.
8. The technique for scales and arpeggios is fundamentally the same, except that in arpeggios wider intervals are covered with slightly larger arm motions than those used in scales.

While feedback of the kind described above would come in handy at the initial stages of learning, i.e., when action takes place slowly and when enough time is available for checking visually and individually the various points on such a list, aural and kinesthetic feedback becomes increasingly important when the movement is refined, noting the decrease in visible movement amplitude usually accompanying such refinement. The restricted usefulness of visual feedback furthermore becomes apparent when passages involving active participation of both the hands have to be mastered, as it is usually not possible to monitor both hands on an equally intensive basis.

Attention should be directed to the fact that Fleisher (Noyle 1987:98) in fact holds that much is to be gained from *eliminating* the visual feedback obtained by looking at the keyboard:

You develop a kind of sense of touch, sensitivity of touch, like a blind person. You play by Braille, you begin to relate to the keyboard in a different way, and you discover that you learn to play with much greater accuracy, much greater physical precision. Another benefit is that one hears much more clearly what is happening ...

Vengerova (Schick 1982:62) even advised her students to practise leaps without looking; "[b]y doing this you learn to gauge the distance better utilizing your other senses".

¹⁵Closely related to this topic is the field of observational learning, where the aim is to learn by watching another perform. This subject will be discussed in Section 5.2.2.2.

Fleisher (Noyle 1987:98) furthermore points out that visual feedback could actually inhibit the more important functions of aural feedback. Pianists should constantly be

... judging, listening to what we're doing so that if what is coming out of the instrument is not what we originally planned, we can adjust what we're doing and get closer to our ideal. And that comes more quickly if one doesn't watch the keyboard.

3.2.2 Extrinsic feedback

*Extrinsic feedback*¹⁶ is "feedback that is artificially added and is not a direct consequence of performing the movement" (Kerr 1982:308). Probably the most common manifestation of external feedback in the learning situation is the feedback given by the teacher to the student. Schmidt (1988b:425) defines five "pairs" of dimensions of extrinsic feedback which provides for a more accurate understanding of this type of feedback. These pairs are

- concurrent vs. terminal feedback
- immediate vs. delayed feedback
- verbal vs. nonverbal feedback
- accumulated vs. separate feedback
- knowledge of results (KR)¹⁷ vs. knowledge of performance (KP)

Concurrent feedback can be distinguished from *terminal feedback* by the fact that the former is delivered during the movement task, while the latter is postponed until after the completion of the task. Temporally speaking, feedback can be delivered either *immediately* or following some time *delay*. *Verbal feedback* is "[p]resented in a form that is spoken or capable of being spoken" (Schmidt 1988b:425) while the opposite is true for *nonverbal feedback*. *Accumulated feedback* reflects "... the average performance for the past few seconds" (Schmidt 1988b:426), while *separate feedback* reports on each moment in the performance.

The important type of extrinsic feedback, termed *knowledge of results (KR)*, is defined by Schmidt (1988b:425) as "[v]erbalized (or verbalizable) post-response information about the outcome of the response in the environment". It should be emphasized that KR is *not* feedback about the movement itself, but rather feedback about the achievement of the goal.

Kerr (1982:77) notes that KR can be *intrinsic* as well, in the sense that goal achievement is evaluated by the performer himself through making use of aural feedback for instance, as was

¹⁶Also sometimes referred to as *augmented feedback*, for example by Adams (1987).

¹⁷It should be pointed out that some authors, for example Adams (1987), use the term KR in a more general sense to include KP as well. Adams's (1987) equivalent for the term KR in the sense used by Schmidt is *outcome knowledge of results*.

described previously: "[a]lthough KR can be either intrinsic or extrinsic, in most studies KR is referred to as an extrinsic source of feedback"; thus its inclusion under the present heading.

Contrary to KR, *knowledge of performance (KP)* is (Schmidt 1988b:425) "[v]erbalized (or verbalizable) post-response information about the nature of the movement pattern". KP is of particular importance for piano playing, as it would typically apply to aspects of the pianist's playing, he would, while engrossed in the intricacies of a difficult passage, only be "... vaguely aware of, such as the behavior of a particular limb in a complex movement" (Schmidt 1988b:426). As in the case of KR, KP can be intrinsic as well; an example mentioned earlier is visual feedback.

The difficulties of learning without KP when only KR is available, as is often the case, are explained by Adams (1987:62) as follows:

... the trainee must use the time between trials to draw inference about pertinent [movement] segments, segment weights, and segment errors in relation to goal error. That most performers attain only a modest level of performance for popular skills over a lifetime of practice is testimony to the difficulty of this inference process ...

Schmidt (1988b:452-453) points out that KR and KP, apart from being informational, can also be thought of as having *motivational*, *guidance* and *associational* functions. As regards the motivational aspect, "KR and KP make the task seem more interesting, keep the learner alert, result in the learner setting higher performance goals, and generally make boring tasks more enjoyable". KR and KP can also be regarded as "guiding factors" in the sense that they have an implicit "instructional" nature, specifying the modifications the corrected movement should incorporate. The associational function of KR and KP involves the use of feedback to establish rules or schema, a topic which will be examined in Section 3.4.2.

In the following sections the characteristics of extrinsic KR and KP will be examined in greater detail.

3.2.2.1 Temporal aspects of KR

This section of the present study is concerned with when it will be most beneficial for the learner to receive KR. According to Schmidt (1988b:454), trials without KR do contribute to learning, but not as much as when KR is given. Both the relative and absolute frequencies at which KR is given is important for learning. Of particular interest for the timing of KR, are three time intervals termed

- the KR delay
- the post-KR delay
- the intertrial interval

The *KR delay* - termed the pre-KR interval by Kerr (1982), Adams (1987) - is "[t]he interval from the production of a movement to the presentation of KR" (Schmidt 1988b:455), the *post-KR delay* - or post-KR interval (Kerr 1982), (Adams 1987) - "[t]he interval of time from the presentation of KR to the production of the next response" (Schmidt 1988b:455), while the *intertrial interval* (or inter-response interval) can be defined as that period in time spanning both the KR delay and post-KR delay; thus "[t]he interval of time from one response to the next in the KR paradigm" (Schmidt 1988b:454).

Considering the various experimental findings on the influence of the length of the KR delay interval on motor learning, Schmidt (1988b:437) points out that "... we must question the relevance of the KR delay variable for motor learning in general". The KR delay interval should however not be filled with other movement activities that could be confused with the task movements, due to the fact that the subject apparently should

... retain in short-term memory the sensory consequences (the "feel") of the movement until the KR is presented, so that the two can be associated. (Schmidt 1988b:439)

Two procedures, both concerned with regulating opportunity for error processing, have been used by closed-loop theorists in studying the significance of the post-KR interval, namely (Adams 1987:60) "... to shorten or lengthen the interval, or to fill the interval with an activity that would either compete with the processing or not". It appears as if the learner in the post-KR delay interval will be actively planning a modified, more correct version of the relevant movement task - therefore, it is expected that systematically shortening the post-KR delay interval should at some point degrade learning, because the learner will not have enough time to prepare the modified response (Schmidt 1988b:440-1). Filling the post-KR delay with secondary task information-processing "... probably decrease performance and learning slightly", according to Schmidt (1988b:454). Increased complexity of KR was shown to affect performance in an adverse way, only when the post-KR interval was not long enough for necessary information-processing to take place (Adams 1987:60). Magill (1988), however, has produced experimental results that contradict this traditional position. His findings (Magill 1988:242) actually suggest that "... interfering with KR processing can actually benefit motor skill learning if learning is viewed as enabling the individual to successfully produce previously unpractised variations of a practised action". Adams (1987:60) notes that the inconclusive results of studies on information-processing in the post-KR interval could have been due to "... a failure to appreciate the speed of error processing in simple tasks".

Intertrial intervals, according to Schmidt (1988b:440), should not be made excessively short; it has been suggested that longer intertrial intervals cause the current solution to the relevant motor problem to "fade" in memory, thus requiring a vigorous effort on the next trial.

Finally, Schmidt's warning (1988b:440) should be heeded that "... much more study is needed of these various intervals, using tasks of varying complexity, before we can claim to understand the processes at work".

3.2.2.2 Precision of KR

Schmidt (1988b:455) describes *precision of KR* as "[t]he level of accuracy with which KR describes the movement outcome produced". Error information can be presented with respect to *direction* and *magnitude* (Schmidt 1988b:447), for example "your wrist is held two inches too high with respect to the keyboard" if the hand position, instead of the sound produced, is seen as some sort of intermediate movement goal. For the present study, it is of interest only to note here that "[w]hile we might think that too much KR precision is harmful for adult learning, the evidence does not support this claim" (Schmidt 1988b:448).

3.2.2.3 Types of KP

Schmidt (1988b:448-451) singles out four types of feedback on performance as of particular importance, namely

- kinematic feedback
- kinetic feedback
- videotape replays
- biofeedback

Of immediate importance for the present study in view of its behavioural emphasis, are the first three types which will hence be discussed in greater detail.

(a) Kinematic feedback

The term *kinematic feedback* refers to "[f]eedback about the movement characteristics or movement pattern produced" without regard to the forces producing them (Schmidt 1988b:455,449). Kinematic feedback is probably one of the most common tools available to the music teacher in his instruction of piano-technical skills;

[c]lever music ... instructors ... seem to be able to sense "what went wrong" and to provide verbal descriptors that can serve as suggestions for change. (Schmidt 1988b:449)

Most kinematic feedback focuses on information that, although not impossible for the subject to observe by himself, is unlikely or difficult to be effectively perceived during execution of the relevant movement pattern.

It is not yet known which forms of kinematic feedback will be most useful to the subject under particular conditions (Schmidt 1988b:450). A reason for this lack in verifiable knowledge could be the traditional emphasis on (outcome) knowledge of results (Adams 1987:62); in the past, the bulk of KR research was concerned with "... movement outcome in relation to an environmental goal", with relatively little attention bestowed on "... refinement of a movement sequence required in getting to the goal" (Adams 1987:61).

At the present time, however, kinematic feedback is the main topic of research in the KP field. Adams (1987:61) regards this type of feedback as having to do with the shaping of movement sequences, a *movement sequence* being "... composed of segments, each of which contributes to outcome, that differ in weight and do not contribute equally to outcome" (Adams 1987:62). Of course, long movement sequences abound in piano playing. Adams (1987:61) lists three different methods of delivering kinematic feedback to the learner:

The *first* method involves showing the learner the pattern of his response sequence only. The learner himself must infer error in the pattern.

The *second* method, the advantages of which have been proven experimentally (Adams 1987:62), requires demonstration to the subject of the pattern of his response sequence along with the ideal pattern that he is to master. The difference between the two then is a measure of error which can be directly observed. It is redoubtable, however, whether such an approach would be effective where it counts in piano playing, because in high-speed, highly refined movements, individual motions of fingers are sometimes hardly visible.

According to Adams (1987:62), the *third* way is commonly employed in the performing arts. It involves giving the learner "... error information for some or all of the segments that make up the movement sequence. An instructor might point out several mistakes that the subject made as he or she advanced to the goal" (Adams 1981:61). The difficulty of learning can be greatly alleviated if the performer can be supplied with such segment KP in addition to KR because "... he or she will then have little left to figure out alone" (Adams 1987:62). It also appears as if identification of that particular segment in the movement sequence with the greatest relative weight, could contribute to facilitate the learning process;

[t]he segment that was most heavily weighted is the big contributor to outcome knowledge of results, and a subject could easily infer that concentration on the segment would be the easiest way to reduce goal error.

The possible use of videotaped performances, which is a means of giving segment KP, will be discussed later in the present section.

While the third method of giving kinematic KP appears to be quite familiar to the field of piano teaching, more research is undeniably required to determine which of these three methods will be most effective - under which particular circumstances - for the learning of piano-technical skills.

(b) Kinetic feedback

Kinetic feedback is "[f]eedback about the force characteristics of a movement" (Schmidt 1988b:455). The importance of kinetic feedback for piano playing can hardly be underestimated, especially as a common problem of piano technique is the exertion of excessive force to depress keys which essentially present little resistance. Generally speaking, however, this direction in motor learning research unfortunately appears to be underdeveloped as well; Schmidt (1988b:451) notes that "[t]he uses of this type of feedback about forces has the potential to be very effective for skills learning, and much more research effort could profitably be directed to this problem".

Prostakoff and Rosoff (1969:6) suggest that the teacher can supply kinetic feedback to the learner of piano technique by holding the hand, forearm or upper arm of the student during a pantomime or actual performance, sensing whether "... the coordination is right - whether the hands, for instance, are alert, too limp, or too eager (in relation to the upper arm) to get to the keys".

(c) Videotape replays

While the use of videotaped recordings of the subject's performance intuitively would be expected to be highly beneficial, according to Schmidt (1988b:449) "... little research evidence exists that this method of presenting KP is very effective"; this could probably be due to the fact that too much detailed information is presented to the subject, the latter not knowing which of the massive number of aspects to attend to. Directed viewing, in which subjects are shown which aspects to pay attention to, may however prove beneficial. As before, this matter requires some further investigation with respect to piano playing.

3.3 Stages of motor learning

Schmidt (1988b:460), following Fitts and Posner (1967:11-15), identifies three stages of motor learning which are respectively termed

- the cognitive phase
- the associative phase
- the autonomous phase

In the *cognitive phase*, or *verbal-motor stage*, the learner is concerned with comprehending the task requirements and planning how the first trials can be accomplished - these are activities which demand considerable cognitive input. Because ineffective strategies are consciously replaced by better ones, "... the performance gains during this phase are dramatic and generally larger than at any other single period in the learning process" (Schmidt 1988b:460). Most of the improvements in this stage are linked to "*what to do* rather than ... the movement patterns themselves"; thus they could be considered "verbal-cognitive in nature". Practice in this phase is usually of a slow nature; "... we have to cajole ... [the mind], prove that the new pattern can be easy" (Slenczynska 1974:30).

The *associative phase*, which is sometimes termed the *motor stage*, can last for many days or weeks, beginning when the learner is ready to make adjustments of a more subtle nature in his movement patterns. The focus of attention now rests on the motor patterns themselves rather than what is to be done.

When the skill becomes automatic in the sense explained in Section 2.4.3.3 - i.e., automatic with respect to some specified secondary task (which is often of a verbal-cognitive nature), the *autonomous phase* of learning has been entered. Characteristic of this phase is that (Schmidt 1988b:461) "... the task can now be performed with less interference from many other simultaneous activities". As an example Schmidt, following Shaffer (1980), cites the concert pianist "... who can ... do mental arithmetic without interference while sight-reading and playing piano music". For the pianist, the benefits of this stage are of a rather more sublime nature: technically difficult passages can be executed "automatically", leaving information-processing facilities free to be devoted to interpretational aspects of the task, for example phrasing and dynamics. Therefore it is unfortunate that this highly important stage almost never is subjected to the scrutiny of researchers, simply because it could take months of commitment for test subjects to become sufficiently highly skilled in the motor task required for the experiment.

3.4 Two motor learning theories from motor systems theory

According to Schmidt (1988b:41), a theory is "[a]n abstract hypothetical explanation for a group of laws and facts", with a *law* being "[a] statement of a stable dependency between an independent variable and a dependent variable". A theory should be generally applicable in the sense that it should not be restricted to only particular tasks, or only a few experimental variables; in fact, "... a good theory of learning should, in a single structure, be able to explain as many ... laws as possible, and without contradicting any of them" (Schmidt 1988b:479).

The two theories that will be presented in this section are associated with respectively J.A. Adams and R.A. Schmidt. By common agreement in the literature, both satisfy the requirements for fulfilled theories of motor learning¹⁸, even though neither of them can explain all of the existing evidence on motor learning (Schmidt 1988b:490).

3.4.1 Closed-loop theory of Adams

3.4.1.1 Adams's closed-loop emphasis vs. the behaviouristic open-loop emphasis

According to Schmidt (1988b:479), the closed-loop theory of motor learning proposed by Adams in 1971 concentrated heavily on the learning of slow positioning movements;

[h]e believed that the principles of performance and learning that applied to these responses were the same as for any other kind of response and that using a well-established set of empirical laws from positioning responses would produce a solid basis for theorizing.

Schmidt (1988b:490) sums up the essential workings of Adams's closed-loop theory as follows:

... the learner acquires a reference of correctness (called the *perceptual trace*) through practice and ... the improvements in motor responding result from the increased capability of the performer to use the reference in closed-loop control.

In contrast to Adams's theory stands the older open-loop model of learning, which can essentially be considered a learning representation

... in the traditions of ... behaviorism. If energizing agents like motivation and the habit strength developed by reinforcement (or knowledge of results) are sufficient, the response occurs, otherwise it does not; there is no appraisal of the response for correctness or an adjustment if it is wrong. (Adams 1987:58)

Although the behaviouristic theories made use of feedback in the sense of associating stimuli with responses - "[t]he response-produced stimuli of one response segment becomes connected to the next response segment as a way of explaining the learning of movement sequences", there was no question of error compensation following the measurement of the correctness of the response, and thus no feedback in the closed-loop sense.

3.4.1.2 Feedback

Two important feedback concepts, associated with Adams's closed-loop theory that also provide considerable insight into the structure of the theory, are

¹⁸In order to keep the present study within manageable scope, less complete hypotheses - described by Schmidt (1988b:479) as "miniature theories", for instance the progression-regression hypothesis and hierarchical control models of learning, are excluded from these discussions.

- the perceptual trace
- the memory trace

These concepts will now be explored more fully.

(a) Perceptual trace

The *perceptual trace*, an internal representation of sensory experience (Swinnen 1988:315), can be regarded as a reference of correctness that is obtained through practice with KR in the following manner (Adams 1987:58, Schmidt 1988b:480): on each trial in the repetition of a motor task, representations of the stimulus component of the feedback produced by the response (Schmidt 1988b:480)

... "leave a trace" in the central nervous system (hence the name perceptual trace).

The nature of this stimulus component can be visual and/or proprioceptive, for example. As each trial gets closer to the required response through use of knowledge of results, the imprinted representation of the feedback, or perceptual trace, becomes more and more alike to the feedback the correct response should have, until finally the perceptual trace represents the feedback qualities of the correct response.

It was pointed out earlier that Adams's theory is concerned mainly with slow positioning tasks. For such tasks, the perceptual trace represents the feedback of the correct position; employing the closed-loop procedure described in Section 2.7 for minimizing the difference between the perceptual trace and the feedback received, will thus result in the correct position for the relevant limb or limbs (Schmidt 1988b:479, Adams 1987:58).

It now becomes clear that the learner has two facilities for error detection and correction, namely knowledge of results and the perceptual trace. In this context, Adams (1987:59) describes knowledge of results as "... error information ... used in relation to the perceptual trace for making the next response different from the last one by having less error".

In fact, to Adams (1987:59) motor learning is essentially a perceptual process with cognitive characteristics as well, because "... knowledge of results and the correspondence between feedback and the perceptual trace, as sources of error information, combine to produce the trial-by-trial changes that constitute learning" (Adams 1987:58).

In order to explain how learners can develop capabilities for error-detection without external help, Adams proposed the idea of *subjective reinforcement*. In a learning setup associated with the latter concept, knowledge of results is omitted; the learner would compare feedback against the perceptual

trace, using the difference representing the error as subjective reinforcement. However, this procedure can only occur provided that the perceptual trace is sufficiently strongly developed and that feedback from the response is strong enough. Also out of limits would be the initial stages of the learning process, because the subject at first does not know what the correct response should be, and therefore needs shaping of the response by an external source (Adams 1987:59).

An interesting implication of the theory of Adams is that errors made while training are detrimental to learning, because the feedback from the incorrect response is necessarily different from that of the correct response when errors are made, resulting in degrading the perceptual trace "... a little bit" (Schmidt 1988b:481). Thus the importance of error-preventing guidance in the process of training should be reckoned with in designing strategies for motor learning.

Regarding the above, Reubart's (1985:80) notion on the importance of first impressions also appears to be of some relevance:

The first auditory and haptic impressions unquestionably register somewhere in long-term memory, and if they are correct registrations, they can be an advantage to memory in performances for years to come. This is as true of auditory memory as it is of haptic memory ...

(b) Memory trace

While the perceptual trace represents the perceptual nature of closed-loop learning, the *memory trace* is nonperceptual, and was devised in the context of the model presently being discussed to compensate for the fact that no feedback is available before the response appears, thus rendering the perceptual trace unusable. The memory trace is defined by Adams (1987:59) as "... a brief motor program that selects and initiates the response, preceding feedback and the use of the perceptual trace". It can therefore be said that the memory trace is used to get the movement started, after which the perceptual trace takes over.

3.4.1.3 Limitations of the theory

According to Adams (1987:60), two main points of criticism have been raised against the closed-loop learning theory - the one having to do with its theoretical construction and the other stating that additional concepts are needed to take into account certain experimental findings:

- (a) ... the theory relies too much on response-produced feedback and consequently fails to consider that movement sequences can be run off centrally without the aid of feedback ...
- (b) ... it fails to consider response variability, not of the random error kind but of the productive kind in which responding is flexibly adapted to a changing situation.

In addition, Schmidt (1988b:481) points out some logical inconsistencies in the theory:

Adams has the perceptual trace providing (a) the basis for placing the limb at the correct target location and (b) a basis for knowing how far that movement was away from the target location after the movement is completed.

But if the perceptual trace determines the positioning of the limb to the best of its "knowledge" at that particular moment, the same perceptual trace can not supply information about its own error with respect to the correct position.

Furthermore, Adams's theory does not take into account the very different uses of error detection mechanisms by slow and fast movements, and in fact can only be used to account for slow, linear-positioning responses. Schmidt (1988b:482) acknowledges the fact that Adams's closed-loop theory, at the time of its proposal, presented a major step forward in the field of motor learning due to the substantial research effort stimulated by it; however, it has been shown "... to have a number of limitations ... and it no longer accounts for the currently available evidence on motor learning".

3.4.2 Schema theory

A *schema* can be defined as "[a] rule, concept, or relationship formed on the basis of experience" (Schmidt 1988b:491). An example of a schema from everyday reading is the so-called "moral" of a story; the essence of the story can be termed the schema for the story, as opposed to the superficial details that is not fundamental to it (Schmidt 1988b:483).

Under the term *schema theory*, which is based on the rather old schema concept, is understood the theory introduced by Schmidt in 1975 to compensate for the shortcomings of the closed-loop theory listed previously (Schmidt 1988b:482). Relying on both generalized motor programs and the concept of schema, schema theory is distinguished from the theory of Adams in using (Adams 1987:60) "... response-produced feedback less than Adams's theory and [being a hypothetical construct] whose behavioral centerpiece is response versatility". Attractive aspects of Adams's theory, like the concern for slow movements, were however retained (Schmidt 1988b:482).

Schmidt (1988b:488) depicts schema theory as

... the theory that says we learn skills by learning *rules* about the functioning of our bodies, forming relationships between how our muscles are activated, what they actually do, and how those actions feel.

In subsequent sections schema theory will be investigated more closely for the purpose of identifying aspects that could be of avail in the process of acquiring piano-technical skills.

3.4.2.1 Two states of memory: recall and recognition

According to schema theory, two states of memory exist for learning: the *recall memory*, which is responsible for movement production, and the *recognition memory*, which is responsible for evaluating the response from the movement¹⁹.

Schmidt (1988b:483) describes the respective functioning of these memory states as follows: for rapid movements, recall memory "... is involved with the motor programs and parameters, structured in advance to carry out the movement with but minimal involvement from peripheral feedback", while recognition memory "... is a sensory system capable of evaluating the response-produced feedback after the movement is completed, thereby informing the subject about the amount and direction of errors". For slow movements, recall memory does not have much of a function, and for those slow movements that are not preprogrammed, the recall state, according to Schmidt (1988b:483), "... merely pushes the limb along in small bursts, with the individual stopping when the response-produced feedback and the reference of correctness match".

3.4.2.2 Two types of schema: recall and recognition

Inextricably intertwined with schema theory is the concept of the generalized motor program²⁰. According to Schmidt (1988b:484), four "items" of information are stored following the performance of a movement by "running" its generalized motor program. These items are:

- the initial conditions regarding the limbs of the learner and the environment before the inception of the movement
- the parameters assigned to the generalized motor program
- KR as representative of the movement outcome
- the sensory consequences of the movement, i.e. "... how the movement felt, looked, sounded ..."

Storage of these items is sufficiently long for two types of relationships or schema to be formed between them, namely *recall schema* and *recognition schema*. Adams (1987:61) concisely describes the roles in motor learning of recall schema and recognition schema as follows:

Recall schema selects the values of the movement parameters that specify the particular movement to be made from among those in the movement category, and the response recognition schema evaluates the correctness of the movement that is made. ... In a particular situation the recall schema reacts to the initial conditions that call for the movement and

¹⁹Compare with the logical inconsistency in Adams's theory described in Section 3.4.1.3.

²⁰Although schema theory does not attempt to explain how motor programs originate.

specifies the parameters, and the response recognition schema is the reference against which feedback from the movement is evaluated for error.

Thus, with knowledge of results which aids in error detection and redefinition of parameters to compensate for error, experience also plays an important role in that stored information involving *inter alia* initial conditions, gained from previous trials, is required to launch the movement.

The concepts of recall and recognition schema will now be examined in greater detail.

(a) Recall schema

Recall schema, which is concerned with the production of movement, is described by Schmidt (1988b:491) as "... the relationship between past parameters, past initial conditions, and the movement outcomes produced by these combinations". These relationships are obtained through a series of trials with different parameters passed to the generalized motor program, resulting in different movement outcomes; following the execution of a sufficient number of trials, the learner begins to see a trend with respect to parameters and outcomes which eventually gives rise to the rule, or schema.

The way in which recall schema are developed, can be explained in a more graphical manner as follows (Schmidt 1988b:484): suppose the forming of rules or schema are represented by a two-dimensional graph²¹ where the horizontal axis represents movement outcome and the vertical axis the individual parameters that are passed to the motor program each time the movement is executed. Any discrete point on the graph thus represents a certain parameter and movement outcome pair. When the generalized motor program is executed a sufficient number of times, i.e. when enough discrete points are available, the line of best fit, which

... perhaps ... [represents] the "direction" in which the "cloud" of points is oriented (Schmidt 1988b:304)

can be regarded as the rule relating input parameters to movement outcome. Every time the movement is executed anew, another point is added to the graph, which causes a slight modification to the rule -

[a]fter each of these adjustments, the stored data are "thrown away," so all that remains of the movement is the rule ... [i.e.] the recall schema. (Schmidt 1988b:485)

Different initial conditions are each accounted for by data and a "line of best fit" of its own.

Actual use of schema occurs as follows: when the learner decides to carry out a movement pattern for which the generalized motor program has been run enough times to allow for schema

²¹The graph representation is of a merely conceptual nature; no particular dimensions can be associated with the different axes.

construction, the desired movement outcome in the environment and initial conditions regarding both environment and the bodily position of the learner are noted. Using the schema or rule that originated through past experience, that particular parameter can be selected which, on substitution in the generalized motor program, will yield the required response for the given set of initial conditions (Schmidt 1988b:485).

Taking into account the above arguments, the usefulness of recall schema is aptly summed up by Adams (1987:60) with regard to everyday motor activities as follows:

... recall ... schema is seen as a categorical concept that yields the ability to hit a tennis ball many different ways to the same place or, more simply, to take several behavioral routes in touching a desk corner.

(b) Recognition schema

Recognition schema can be described as (Schmidt 1988b:491) "... the relationship between past initial conditions, past movement outcomes, and the sensory consequences produced by these combinations". Used in a manner analogous to recall schema, the individual will select a movement outcome and determine the state of the initial conditions before performing the movement. Use of the recognition schema will then enable him to predict the sensory consequences of the movement; these expected sensory consequences can be regarded as analogous to Adams's perceptual trace that was discussed in Section 3.4.1.2.

3.4.2.3 Recall and recognition schema incorporated into the global organization for motor learning

In Figure 3.1 a flow diagram representation by Schmidt (1988b:487) is shown for the critical elements in a movement performance, accounting for both rapid and slow movements.

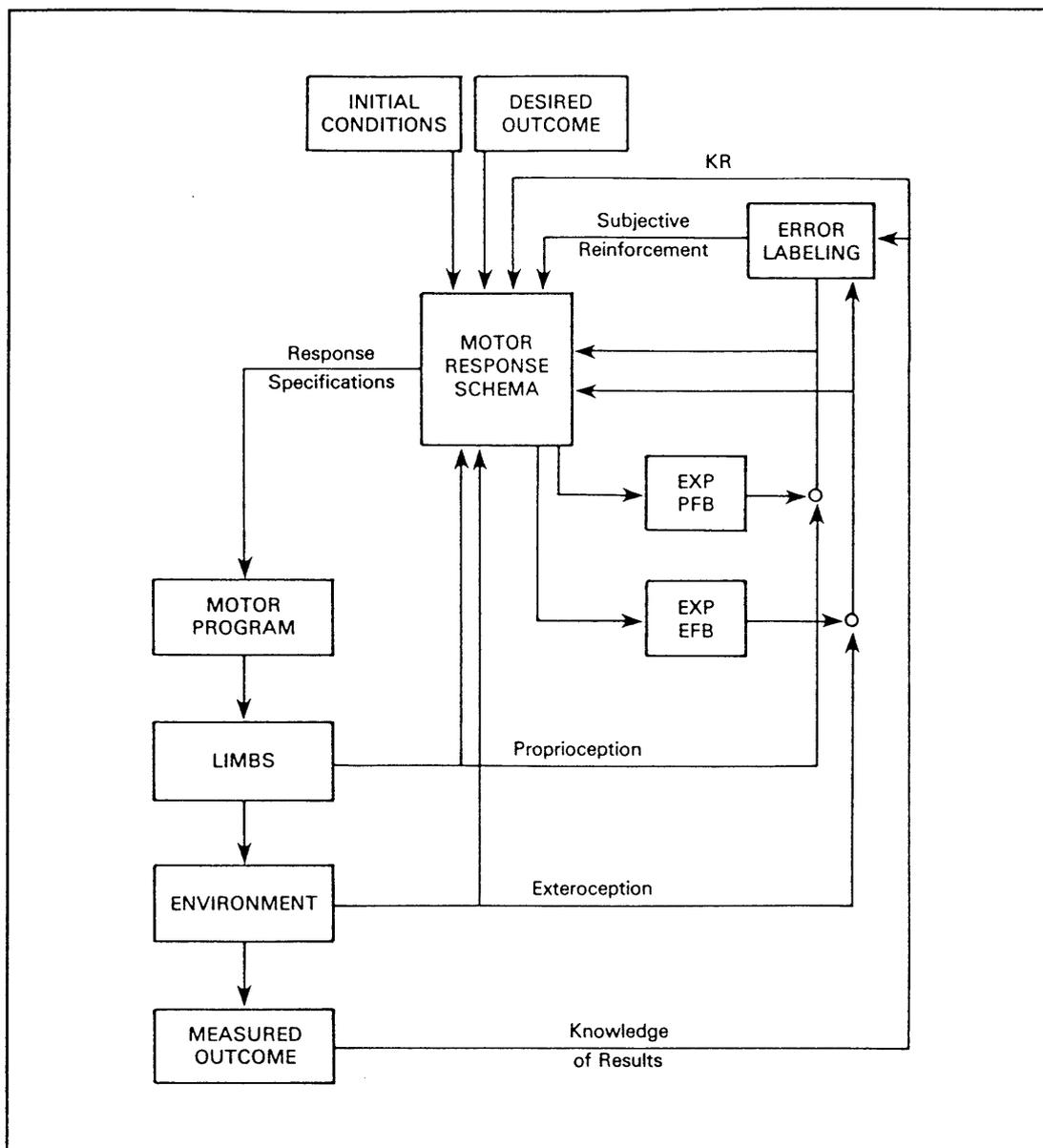


Figure 3.1 Flow diagram showing the schema theory point of view to critical elements in a movement performance (EXP PFB = expected proprioceptive feedback, EXP EFB = expected exteroceptive feedback). (Reproduced from Schmidt, 1988b:487)

For fast movements, the system receives input information about initial conditions and the required response, causing the system to point out the parameters for the general program and the expected sensory consequences in terms of, for example, proprioceptive feedback and exteroceptive²² feedback. After execution of the motor program, the actual proprioceptive and exteroceptive feedback are compared to their respective expected states. Differences represent errors which, according to Schmidt (1988b:486-487), are delivered back to the information-processing stages, serving as

²²*Exteroceptive feedback* consists of information about events outside one's own body (Schmidt 1988b:147).

subjective reinforcement.

Subjective reinforcement is considered to be the prime factor in producing the movement patterns for slow movements (Schmidt 1988b:487):

... the expected feedback sources represent the criterion of correctness, and the feedback compared to them gives ongoing information about errors during the response. Then, the individual moves to a position such that the error is as small as possible, indicating that the individual's limbs are on target. Thus, even though the slow movement is actively produced, it is thought to be governed by recognition memory and the recognition schema.

It is not clear at the present stage how knowledge of the rather elaborate model of learning represented in Figure 3.1 can aid the learner of piano playing; more research in this regard is clearly required.

3.4.2.4 Variable practice

Schema theory supposes that practising a variety of movement outcomes with the same program will lead to more widely spaced points on the "graph" for schema development described in Section 3.4.2.2, resulting in greater certainty as far as the characteristics of the "line of best fit" is concerned²³. Thus, "... varied training would produce the best performance in transfer" (Adams 1987:61); experimentation to verify this prediction has produced "... findings [that] are mixed, but tend to be positive". These positive signs have been found to be stronger with children; a possible reason for this phenomenon, according to Schmidt and confirmed by Adams (1987:61), is that "... adults have had so much varied training in their extraexperimental lives that the varied training they receive in the laboratory adds little to the capabilities they already have".

3.4.2.5 Motor learning may be primarily rule learning and not learning of responses

Experimental findings involving open skill motor tasks in particular, have shown that learners who have been subjected to varied training, can produce novel responses almost as accurately at the first attempt as they would have been produced after repeated practice, suggesting that "... motor learning may be primarily rule learning and not the learning of specific responses" (Schmidt 1988b:488).

²³But see also Section 5.3.5.

3.4.2.6 Limitations of the theory

A major limitation of schema theory - in particular with respect to the action viewpoint - is its emphasis on the generalized motor program (Adams 1987:61); while Schmidt (1988b:489) stresses the fact that he believes in the generalized program idea, he nevertheless states that

... the entire structure is vague in terms of how the program is formed in the first place, how the rules about parameters and sensory consequences are developed and used, how the individual makes the first response before any schema can exist ... [I]f the generalized motor program idea might later be shown to be incorrect, so too will be schema theory, as the theory depends strongly on it.

The other problem with schema theory arises in the laboratory. It goes without saying that a theory of learning should be able to account for findings in laboratory experiments involving motor skill research, because theories are supposed to be backed by experimental evidence, and in some cases even originate from such evidence. Due to the way in which schema are formed, they can be regarded as rather stable rules which could take years to establish. To explain the motor learning that occurs in laboratory experiments, schema are required to change rather drastically between trials, in order to account for the more effective choosing of generalized motor program parameters that is associated with an increase in learning. This notion of radical changes in schema is not compatible with the stable-rule character of schema (Schmidt 1988b:489), presenting a serious problem for the theory.

While schema theory does offer some marked improvements over the closed-loop theory of Adams, Schmidt (1988b:489) unequivocally states that the theory does not offer a complete understanding of the experimental findings on motor learning; in fact, "[s]ome logical problems need to be solved, and it is not clear that this can be done without discarding the entire theoretical structure".

3.4.2.7 Application of schema theory to musical instrument performance

Owen's (1988) concept of schema theory is rather different from that of Schmidt in that it is based on a hierarchical control model of learning, which is considered by Schmidt to be one of the less complete hypotheses of learning, i.e. not a fulfilled theory in the sense of the theories of Adams and Schmidt. For the sake of completeness and in view of the lack of research pertaining to musical instrument learning on this matter, some discussion will nevertheless be devoted to Owen's work. It is of course hoped that Owen's findings, which only pertain to orchestral and band instruments, will have some relevance for piano playing as well; some more research is however required before any conclusive statements can be made in this regard.

Based on the interpretation of schema by LaBerge, Owen (1988:1-4) holds that schema are a fairly small set of rather abstract concepts of movement patterns stored at an executive memory level. A second memory level, called coordinative structures, store the needed information to turn the general concepts from the executive level into real and specific movements. The coordinative structures obtain their information by effectively getting programmed with specific muscle movements when a new skill is learned.

Scale learning and performance can in this context be explained as follows (Owen 1988:3):

In the early stages, the scale is learned a single note at a time, along with its fingering. Eventually, the notes become linked together in a more abstract form which could simply be called "scale" [i.e., the schema]. When an experienced performer encounters the scale in printed music, the executive level may furnish the abstract concept of scale to the coordinative structures, where the specific set of movements necessary to perform the scale have been stored. It is not necessary for the performer to think of the notes of the scale individually and how to produce them, since that information is stored at a different level.

It is of some interest to note Owen's (1988:31) view that schema theory influences perceptual learning as well; the latter topic is however not a matter for consideration in the present study.

Instruction based on motor schema theory was found by Owen (1988) to have produced significant improvements in practice techniques for undergraduate performers in brass, woodwinds, and stringed instruments. Of the three test groups - which included the control group which received no instruction on practice techniques, the second group which received instruction on "traditionally" accepted methods of practice, and the third which was supplied with both applied practice techniques and techniques based on applications of motor schema theory, the motor schema theory group at their own initiative practised more than the others, and also reported "more favourable feelings" concerning the formation of goals, the practice strategies used and the balance of mental and physical practice (Owen 1988:81-82).

The conclusions reached by Owen (1988:8283), based on a statistical analysis of his data, which are the most relevant for the present study, are listed here:

1. Motor schema theory of learning is valid in teaching of practice strategy.
2. Differences apparent at the conclusion of the experiment were due to combined effects of instruction, rather than individual components of the instruction.
3. Understanding of motor schema theory concepts takes relatively long.

Hong (1989:82-83), however, "question[s] the internal validity of the resultant data" on a number of grounds, including uncertainty about whether the traditional practice group and the motor schema group actually *did* use these techniques as discussed by the researcher. Other questions that remained unaccounted for in the experiment were; the practice techniques employed by the test subjects before

the experiment; whether the results would have been different if participants had been grouped according to the year of study; and whether "individual aesthetic sensitivity and kinesthetic response of subjects result[ed] in suspect data' ...".

It is nevertheless worthwhile to reproduce here some of Owen's (1988:84 ff.) suggestions on musical instrument practice based on his concept of motor schema theory. More research is needed to determine whether these considerations are indeed valid for piano practice as well; no apparent reasons exist, however, for regarding them as particularly inappropriate to piano playing.

With respect to the coordinative levels of control, Owen (1988:84-85) suggests that the learner should "[b]uild from smaller to larger units" in the acquisition phase of learning, connecting these smaller units into progressively larger ones: "[f]or example, individual notes could be linked into a scale, or a number of motives could be linked into a phrase". Errors should be avoided due to their detrimental effect on schema forming. In order to promote the development of "varied" schema, attempts should be made to practice as many links between musical units as possible:

Students might practice from the middle of one phrase to the middle of another, build the phrase from the end backward to the beginning by practicing one measure at a time, or locate boundaries in the playing when stops occur, or where errors occur.

According to Owen (1988:85), the executive level can be developed during practice by trying to relate the material currently being practised to material practised before, for example by recognizing familiar movement patterns. A passage consisting of a number of different scales, for example, may be related to scale patterns learned previously, which will help "... a new image [to] be formed, and stored at the executive level in a general way" (Owen 1988:86). Efforts should be made to constantly cultivate larger, more extensive schema, for instance by linking subsidiary phrases of a section together, or by linking smaller units such as scales and chords together in more sizable segments.

3.5 Motor retention and memory

Vague descriptions of "finger memory" and the other types of memory involved in piano playing abound in the literature on piano technique, a typical example being Neuhaus's (1973:147) distinction between two types of memory, namely "... the musical (spiritual) and the muscular (bodily)" memories. The purpose of the present section is to investigate the concepts of motor memory and retention from the motor behaviour science viewpoint, with particular emphasis on their description in terms of man/machine characteristics.

Retention is defined by Kerr (1982:312) as "the persistence of a skill over a period of no

practice". Schmidt (1988b:512) describes *motor memory* as "... the persistence of the acquired capability for responding"; therefore, memory can be distinguished from learning in that the latter has to do with the acquisition of certain skills, while the former is concerned with maintaining these skills over a period of time. Losses in memory are termed *forgetting*.

Schmidt (1988b:493-494) emphasizes that, contrary to the notion held in some branches of psychology that memory is synonymous to a place where information is stored, motor memory should rather be seen as the *capability* for responding; thus, "[d]epending on one's theoretical orientation about motor learning, motor memory could be a motor program, a reference of correctness, or a schema that was acquired during practice".

While memory and forgetting are theoretical constructs in the field of motor learning, *retention* is a behavioural concept indicating persistence or lack of persistence in performance. According to Schmidt (1988b:494), "[i]t is the test that tells me whether or not memory has been lost", i.e. a decrease in performance proficiency after some retention interval could indicate that loss of memory has occurred, provided that the usual factors affecting performance, like fatigue, are accounted for.

Contrary to the situation in the field of verbal learning, mechanisms for forgetting in motor learning have not been studied intensively, and thus are not well understood.

3.5.1 On theories of forgetting

While most of the theoretical work on forgetting in the literature pertains to verbal learning, Schmidt (1988b:497) singles out two theories that may be of interest to motor forgetting, namely

- the trace-decay theory
- interference theory

The *trace-decay theory*, which is the oldest theory of forgetting, simply holds that information is forgotten because it is not practised, the forgetting process manifesting itself in a "decay" of the information with time. While the theory is based on little more than intuitive hunches, it accounts well for the effects of disuse and the passage of time on retention (Schmidt 1988b:497).

Interference theories of forgetting state that memory is degraded by the occurrence of other events that intervene between the learning of a response and its retention.

Two fundamental types of interference are distinguished, namely *retroactive interference* and *proactive interference*. Retroactive interference, which can also be regarded as a form of negative

transfer, is (Schmidt 1988b:513) "... a source of forgetting caused by learning imposed between the original learning and the retention test for a to-be-remembered task", while in proactive interference forgetting is induced by some event occurring *before* the first learning of the to-be-remembered task. This event occurring beforehand could be, for instance, a skill learned through a lifetime of movement behaviour which inhibit learning of a new, different skill.

Schmidt (1988b:499) points out that, while scientists involved in verbal research are in general convinced that the bulk, if not all, of forgetting is due to either retroactive or proactive interference, experimental *support* for the interference theory does not necessarily prove that it is correct. Neither has sufficient focus been aimed at retroactive or proactive interference with respect to motor skills to contribute significantly to an understanding of motor forgetting.

3.5.2 Long-term motor memory

It has been pointed out previously that piano playing displays both continuous and discrete skill characteristics. In the present section, therefore, some brief remarks will be made on these skills with respect to their retention characteristics over long retention periods, i.e. weeks or months.

Continuous skills are extremely well retained over long periods of retention, which could add up to years of no practice. Examples from everyday life of such skills are swimming and riding a bicycle. Discrete tasks, on the other hand, are much more easily forgotten. The reason for this discrepancy is not clear; according to Schmidt (1988b:512), "[p]erhaps the difference is based on the idea that continuous tasks, with more practice time in a typical experiment, have more resistance to forgetting because they are learned more completely".

The fact that motor skills are generally well retained, can perhaps be explained by noting that motor skills are very specific, even to the extent that skills apparently much alike visually, could in fact have little in common. Thus it seems relatively unlikely that a skill in the process of being learned, will suffer from interference due to elements in common with other skills learned previously, implying that the learning process will proceed unhindered (Schmidt 1988b:503).

3.5.3 Short-term motor memory

According to Schmidt (1988b:512-513), an active research interest was maintained in this subject in the 1970's. Research efforts, apparently not of much interest for piano playing, were concentrated *inter alia* at once-presented movements and linear-positioning tasks, showing "... rather rapid

retention losses, increased retention loss as the retention interval is increased to about 60 sec., and decreased losses as the experience at the target is increased".

It has been pointed out in Section 2.3.2 that the conceptual distinction between long-term and short-term motor memory is not regarded as of much significance at the present time. Apart from many experimental design problems preventing the clarification of short-term motor memory, Schmidt (1988b:508) states that

[s]uspicion grew that much of the motor short-term memory paradigm was not motor at all, but rather was concerned with the retention of sensory information about the feedback associated with the target position.²⁴

Thus Schmidt (1988b:508) depicts the current status of the concept of short-term motor memory as a matter of merely academic interest, the "rise and fall" of which the "educated student of motor behavior should know something".

3.5.4 Warm-up decrement

In conclusion to the section of the present study dealing with retention and motor memory, it is worthwhile to direct some attention to the phenomenon of *warm-up decrement*, which is described by Schmidt (1988b:513) as "... a retention loss caused by the imposition of a short rest in a series of practice trials". Experimental findings point to the *set hypothesis* as the most probable explanation for this phenomenon. This view holds that (Schmidt 1988b:509)

... the loss of skill is related to the loss of some temporary internal state(s), or *set*, that underlies and supports the skill in question. ... [M]emory of the skill is not lost over the rest period; or perhaps very small memory losses do occur, but they are far too small to account for the large decrements seen.

Although severe, the decrement is usually short-lived, and it is usually removed relatively quickly through practice.

Warm-up decrement is relevant in particular for high-level performance activities, where activities are either interrupted by rest, or major changes in the nature of the task takes place. Perhaps the most obvious example from the field of piano playing is that of performing a concert in public. Short rest periods occur between movements of works, and rather longer rest periods between the works themselves - the longest usually being the interval, while dramatic changes in the nature of motor activity could manifest themselves when a classical period work (a Mozart sonata), is followed by a virtuoso piece from the Romantic repertoire (a Liszt *Hungarian Rhapsody*).

²⁴The short-term motor memory paradigm is described by Schmidt (1988b:504-505). Due to the fact that neither it, nor the concept of short-term motor memory for that matter appears to be of particular relevance for the problems of piano playing, its discussion is omitted here.

Whether the effects of warm-up decrement can be eliminated, would depend on the question whether performers can adjust their own sets of internal states. According to Schmidt (1988b:512), "[t]here is no evidence on this point, but it would seem so". In piano playing, it is possible that mental practice²⁵ could have a set-reinstating effect, while Schmidt does not rule out the possibility that "... these self-generated set-reinstating capabilities must be learned". In any event, finding solutions to the many unanswered questions in this area should hold considerable benefits for performers, "... because the decrements are particularly large".

3.6 Summary and conclusions

Intrinsic feedback is essential for motor learning in piano playing. But the use of intrinsic feedback itself requires some learning, as the student has to be taught purposefully to deploy his facilities for intrinsic feedback to their fullest extent. One of the two most important types of intrinsic feedback in piano playing is aural feedback, which involves the pianist's capability for self-hearing. Listening to oneself is a process involving various subtleties; more often than not pianists only hear what they expect to hear. Probably of equal importance is kinesthetic feedback, which involves the monitoring of sensations in the muscular playing apparatus. Visual feedback is only of restricted usefulness because of the smallness of the movement amplitudes involved in piano playing. Some authors are of the opinion that visual feedback should be relegated to only a minor role player in piano playing, or even eliminated as far as possible, in order not to interfere with aural and kinesthetic feedback.

Knowledge of results and knowledge of performance, whether given by a teacher or inferred by the learner himself, are fundamental components of the learning process.

The timing of the giving of extrinsic knowledge of results was investigated with respect to the completion of the current trial and the beginning of the next trial. Apparently, the precise amount of time that lapses during training from completion of the trial to the giving of KR (or KP) is not of critical importance. It is however recommended that this interval should not be filled with other movement activities in order to enable the learner to retain the "feel" of the movement until its KR is given. The post-KR interval should be long enough for the next movement to be planned; contrary to expectations, it was found that filling this interval with secondary information-processing activities could strengthen the ability of the learner to produce *impromptu* variations on a previously learned motor task. Further research is necessary, both to obtain more conclusive information on the significance of the KR delay and post-KR delay for learning, and to determine how these results relate to piano-technical learning.

²⁵This topic will be examined in Section 5.5.

Kinematic feedback, kinetic feedback and videotape replays were identified as means for supplying extrinsic KP to the learner. While all three methods apparently are in use in the field of piano teaching, more research is required to determine their relative effectiveness as well as the circumstances under which they deliver optimal results. It appears as if information with respect to errors in the movement segments that comprise a movement sequence in piano playing, as well as identification of the segment with the largest relative weight, can be of considerable use in reducing goal error through kinematic KP; this suggestion however stands in need of experimental verification. The field of kinetic KP in motor behaviour science - and consequently in piano playing - appears to be under-researched as well. Few findings exist to support the effectiveness of videotape replays for general motor skill learning, the lack of effectiveness probably being due to the fact that learners are overwhelmed by the amount of information they are presented with.

The closed-loop theory of Adams was described. Unfortunately, its validity is limited to slow movements; Adams's premise that the principles underlying the learning of slow positioning movements are the same for any other types of response has proved to be incorrect. The failure of the theory to consider the possibility of the central control of fast movement sequences through motor programs, its lack of structures to account for response variability, and the logical inconsistency regarding the use of the perceptual trace for subjective reinforcement, makes Adams's theory an unlikely candidate to be used as a basis for learning of the richly-varied movement patterns required in playing the piano.

Schmidt's schema theory improves on Adams's theory in that it accounts for centrally-driven, rapid responses through the generalized motor program, as well as response variability by means of recall schema. Attractive features of Adams's theory, like the concern for slow movements and the concept of the perceptual trace - accounted for here by the recognition schema concept - are retained. Experimental findings on schema theory's premise that variable practice will produce the best results in motor learning tend to be positive. The great accuracy with which learners subjected to variable practice before can sometimes produce novel responses, has lead followers of the theory to believe that motor learning may be primarily the learning of rules (schema) and not responses. Practical experience from piano playing tends to support this notion: if a pianist has practised ten different major scales for some time, it is hardly likely that he will have excessive trouble mastering an eleventh. A major limitation of the theory is its heavy reliance on the concept of the generalized motor program. Also, the radical changes expected of schema to account for laboratory learning seem to contradict the stable nature assigned to them by the theory. It is not clear how knowledge of a schema model of motor learning, which can be rather elaborate, can aid the learner of piano technique; more research is clearly needed to clarify this matter.

A less sophisticated version of schema theory which is based on a hierarchical control model for learning was briefly described. While empirical research findings, directed at whether practice methods based on this version of schema theory improve effectiveness in musical instrument practice, are available, it was not shown beyond doubt that the increases in learning that was observed, can indeed be attributed to the schema theory influences.

It was pointed out that, contrary to the situation in the field of verbal learning, the processes of forgetting in motor learning are not well understood. Continuous skills are usually extremely well retained over long periods of no practice, while discrete skills are more easily forgotten - more research is necessary to determine whether these findings hold for piano playing as well, which of course can have both continuous and discrete components. It was pointed out that, apparently, the concept of short-term memory is currently held to be of little more significance than mere academic curiosity. Warm-up decrement was found to be a phenomenon that is to be reckoned with especially by pianists performing in public; insufficient research findings were available to serve as a basis for valid suggestions on the minimization of its effects.