CHAPTER 2

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

2.1 Introduction

2.1.1 The concept of movement

Schmidt (1988b:17) defines[1] *movement* of humans and animals as "[c]hanges in joint angles, the position of the entire body, or both ..."[2]. Movements can be divided into two categories: those that are "primarily genetically defined", i.e. inherited, and those that are learned through considerable practice and/or experience (Schmidt 1988b:3). The latter type of movements is referred to as motor skills[3]. Piano technique can be considered a compendium of highly-evolved motor skills; it is also sometimes referred to in the methodological literature on piano playing in the singular as *a* skill.

2.1.2 The study area of motor control

Motor control is defined by Schmidt (1988b:17) as that "... area of study dealing with the understanding of the neural, physical, and behavioral aspects of movement", while the interrelated field of *motor behaviour* can be considered "[a]n area of study stressing primarily the principles of human skilled movement generated at a behavioral level of analysis".

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[1]This definition will be somewhat extended, as well as critically reconsidered in Chapter 4, which deals with the action approach to motor control.

[2]A *joint* is "a point of contact between 2 or more bones of an animal skeleton together with the parts that surround and support it" (The Penguin English dictionary 1985:451).

[3]Since skilled motor behaviour usually implies that motor learning has taken place, the term *motor skill* will be defined in more formal terms under the heading of motor learning, i.e. in Section 3.1.1.1 in particular.

In the 1970's, motor behaviour research strongly tended toward the field of cognitive psychology in reaction to the oversimplified stimulus-response (S-R) theories of movement prevalent before. The influence of cognitive psychology manifested itself in the relinquishing of a *task orientation* to movement research, "... which focuses primarily on the effects of variables on the performance of certain motor tasks", for a *process orientation*, "... which focuses on the underlying mental or neural events that support or produce movements" (Schmidt 1988b:14).

Sidnell (1986:10) points out that, for the purposes of the music educator or musician wanting to learn more about motor problems pertaining to musical performance through studying paradigms[4] investigated in the psychological literature, the latter paradigms usually being unrelated to music, "[t]here is much research in motor learning and behavior - in fact, too much". In this chapter[5], therefore, the inevitable inclusion of certain subjects and the exclusion of others have been guided by Schmidt's (1988b) proportional distribution of attention to significant, and less significant, information. Furthermore, the approach is, as phrased by Adams (1987:41), "... unashamedly behavioral"; while, as noted in Section 1.4, the emphasis here is not on the intricate workings of the central nervous system or the physiology of movement, the occasional reference will be made to these matters for the purposes of elucidation, when deemed necessary.

2.1.3 Classification of motor behaviour

Two reasons can be stated (Schmidt 1988b:45) for the necessity of employing classification systems of motor responses (or motor skills) when applying scientific method to the study of motor behaviour, the first of which is to facilitate communication within the scientific community. The second reason is that the laws of movement behaviour are not independent of the kind of motor task that is performed - " ... the relationship between certain independent and dependent variables is often different for one kind of task or behavior as compared to another".

Schmidt (1988b:45) singles out two important classification schemes for motor responses, namely

- the continuous/discrete/serial dimension
- the open/closed dimension

[4]A paradigm, or law, is "... [a] statement of a stable dependency between an independent variable and a dependent variable" (Schmidt 1988b:41).

[5]As well as Chapter 3, which deals with motor learning as seen by the motor systems approach.

2.1.3.1 The continuous/discrete/serial dimension

Discrete movements have a recognizable beginning and end - examples of discrete movement tasks with different temporal lengths, which are generally very short, are throwing, pressing a key on the keyboard, or signing one's name.

Continuous movements, on the other hand, are defined as having no recognizable beginning and end. Execution continues more or less uninterrupted until the response is arbitrarily stopped (Schmidt 1988b:46). Examples of continuous movements are swimming, jogging and tracking tasks. Tracking tasks[6], which can be considered a common kind of skill which is often tested in the laboratory, are described by Schmidt as follows: "[the tracking task] ... is characterized by a pathway (track) that the individual is to follow and some device that the individual attempts to make follow the track via certain limb movements". In driving a car, for instance, the road is the track and the car the device that is to follow the track.

Finally, *serial movements* are neither discrete nor continuous, but should rather be considered as consisting of a series of discrete movements strung together. Examples of serial movements are starting a car, and some tasks on production lines in industry (Schmidt 1988b:47).

It appears as if piano playing can be regarded, due to its complexity, as a kind of movement task that displays both serial and continuous characteristics. Seen as a serial task, depressing of the various keys or simultaneous depressing of groups of keys can be considered the constituent series of movement elements. Its continuous facet is perhaps most clearly displayed through the fact that action continues uninterrupted once a piece is embarked upon. Especially high speed, *perpetuo moto* type figures, alike to for instance the quasi-arpeggiated accompaniment found in Chopin's *Etude* Op. 25 No. 2 which is sustained throughout the whole piece, would intuitively seem to be a performance task of a continuous nature, rather than a series of discrete movements - pressing the individual keys comprising the notes of the accompaniment - strung together.

2.1.3.2 The open/closed dimension

An alternative method for classifying movement skills is through observing environmental predictability. *Open skills*, for example boxing, are skills "... for which the environment is constantly (perhaps unpredictably) changing, so that the performer can not effectively plan the response", while

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[6]The description of tracking tasks is included here in order to clarify further references that are made in this thesis to experiments involving tracking.

closed skills are those skills for which the state of the environment can indeed be predicted (Schmidt 1988b:47). Included among the latter type are those skills that are executed in a variable environment, but where the changes are essentially predictable. Somewhere between open and closed skills exists a class of skills with environments that can be considered semi-predictable (Schmidt 1988b:48).

The usefulness of any attempt to classify skills according to their open and/or closed characteristics becomes apparent when the following three questions posed by Schmidt (1988b:48) are considered:

1. Should open and closed skills be taught differently?
2. Do different individuals perform better in either the one or the other?
3. Do closed and open skills have different laws of performance?

While superficial considerations could lead the observer to regard piano playing as unequivocally closed (the positions of keys and the sizes of keys are the same on all pianos), when "trying out" different pianos some differences can indeed be observed, not the least of which is the fact that the heaviness of touch on all pianos is different. Furthermore, the acoustics of the room in which the piano stands as well as the presence or absence of an audience - and its degree of quietness - can have a marked effect on the quality of aural feedback that is available to the performer. In particular, the performer may not be able to hear himself properly, or the sounds that he produces "sound differently" in the immediate vicinity of the instrument than some distance away from it. A common complaint among pianists is the fact that different sections of the keyboard range may differ in volume strength; thus the bass may be predominant on a certain piano, while the top notes could stand out excessively on another. Even pedal actions are often found to differ among pianos. At a more sublime level, pianos also differ considerably with respect to the variety of tone colours that can be obtained by the accomplished pianist. It is therefore not surprising that Stangeland (1981:33) regards the success of any performance as greatly dependent on the instrument at the disposal of the pianist:

> Even an exemplary re-creation of the composer's score on the part of the pianist can be ruined if the instrument is inadequate; worse yet, it is unlikely that the pianist can achieve anything approaching an exemplary performance on such an instrument, no matter how thorough the preparation or how inspired the pianist may be.

From the former arguments it is clear that piano playing can be associated with a semi-predictable environment, a viewpoint which is shared by Bridges (1985:85). But whether piano playing is regarded as a closed or semi-closed skill will depend on the nature of the learner's involvement with music. For the person who plays at home for his own enjoyment, piano playing is a closed skill. For the concert pianist, who almost daily is required to adjust to different pianos, piano playing is a semi-closed skill. The term semi-closed, rather than semi-open, is used to indicate that piano playing is predominantly closed; even if an unknown instrument is to be used, most performers should be able to familiarize themselves within a relatively short period beforehand (or even during the first piece on the recital program) with the instrument's touch, sound quality, and also the most obvious of its fallacies. After becoming acquainted with the instrument in this manner, the pianist's environment is not nearly as unpredictable as the environment normally associated with open skills, such as fencing.

The question arises whether piano technique is indeed instructed with the semi-closed nature of piano playing accounted for; apparently this is not the case. More research is needed to determine the nature such instruction should take on.

2.2 The measurement of movements

In order to place theories of and experiments on motor control in the proper perspective, it is necessary to have some idea of how the characteristics of movements are quantified and/or qualified, i.e. measured. This principle is expounded on by Schmidt (1988b:19) as follows:

> ... to truly understand the principles of motor control and learning, it is essential to know where the research results come from, how they were achieved, what the limitations were on the techniques used to generate them, and how generalizable these results are to other situations.

According to Schmidt (1988b:50-51), the measurement of movements can be approached in two different ways, namely

- measurement of the characteristics of the movement *per se*
- measurement of the degree of success in achieving the goal the movement was originally intended for

In the following sections, these approaches will be described more fully.

2.2.1 Describing movement characteristics

Characteristics of simple movements are very often described through the use of a set of measurement techniques termed *kinematics*, which can be described as (Schmidt 1988b:51)

> ... the description of "pure" motion, without regard for the forces and masses that are involved. As applied to movement behavior ... kinematic measures are those that describe the movement of the limbs and/or the entire body.

There are obviously many different variables that can be recorded for describing movements - Schmidt points out *inter alia* the respective locations of the various limbs involved in the movement, angles of the joints and the time relation between the movement in one joint and the movement in another. Devices that are used in the laboratory to gather this data are described by Schmidt (1988b:51-55)[7]; these include electromyographic (EMG) recordings of electrical activity from muscles involved in executing the movements under consideration.

Biomechanical motion analysis techniques were used by McArthur (1988:1692-A) to investigate certain movement patterns in the execution of an elementary piano piece; while an awareness of the use of such methods in the study of piano playing is certainly desirable, a detailed discussion of these techniques is not of particular interest for the purposes of the present study.

2.2.2 Describing movement outcome

Generally, assessment of movement outcome has bearing on the movement in relation to an object or another performer in the environment (Schmidt 1988b:56). Movements do however exist for which the relationship with the environment is not that directly observable, for instance dancing, or mannerisms in piano playing. The achievement of movement goals can be evaluated in terms of three fundamental variables, namely

- error
- speed
- response magnitude

In subsequent sections these variables will be discussed in greater detail.

2.2.2.1 Measures of error

Errors in movement can be expressed in terms of certain mathematical quantities. Some important error measures are (Schmidt 1988b:56-60,72)

> ... *constant error* (a measure of average error or bias), *variable error* (a measure of consistency), *total variability* (a measure of overall error), and *absolute error* (also a measure of overall error).

2.2.2.2 Measures of speed

Measures of *speed* are used "... when accuracy is less important and when rapid actions are critical" (Schmidt 1988b:72). Important indicators of movement speed are *reaction time* (RT)[8] and *movement time* (MT).

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[7] These laboratory techniques *per se* are not of immediate relevance for the present study.

[8] Reaction time is also an extremely valuable indicator in the study of human information-processing, as will be pointed out in Section 2.3.

Reaction time is defined by Schmidt (1988b:64) as "... a measure of the time from the arrival of a suddenly presented and unanticipated signal to the *beginning* of the response to it". The temporal location of the RT in the so-called *reaction time paradigm* is shown in Figure 2.1[9]. In the discussions by some authors, the division of RT into its *central*, i.e. decision, and *peripheral*, i.e. musculature, components is employed. Associated with the central component is the *premotor RT* and with the peripheral component the *motor RT* of the movement. *Premotor RT* is defined as (Schmidt 1988b:64) "... the interval from the signal to the first change in EMG ... [It] is thought to represent central process (e.g., perception, decisions)".[10] The presence of a premotor RT indicates that the command to move the muscle has not yet reached the muscle. The *motor RT* of the movement represents processes in the muscle itself; it can be considered an indication of the time from the appearance of electrical activity in the muscle to the actual, observable occurrence of the response; Kerr (1982:218) describes it as "... the interval between the arrival of ... [the] neural signal at the muscle and the actual contraction of the muscle that initiates the response or the first observable movement".

Movement time (as diagrammatically explained in Figure 2.1) is defined as (Schmidt 1988b:65) "... the interval from the initiation of the response (the end of RT) to the completion of the movement".

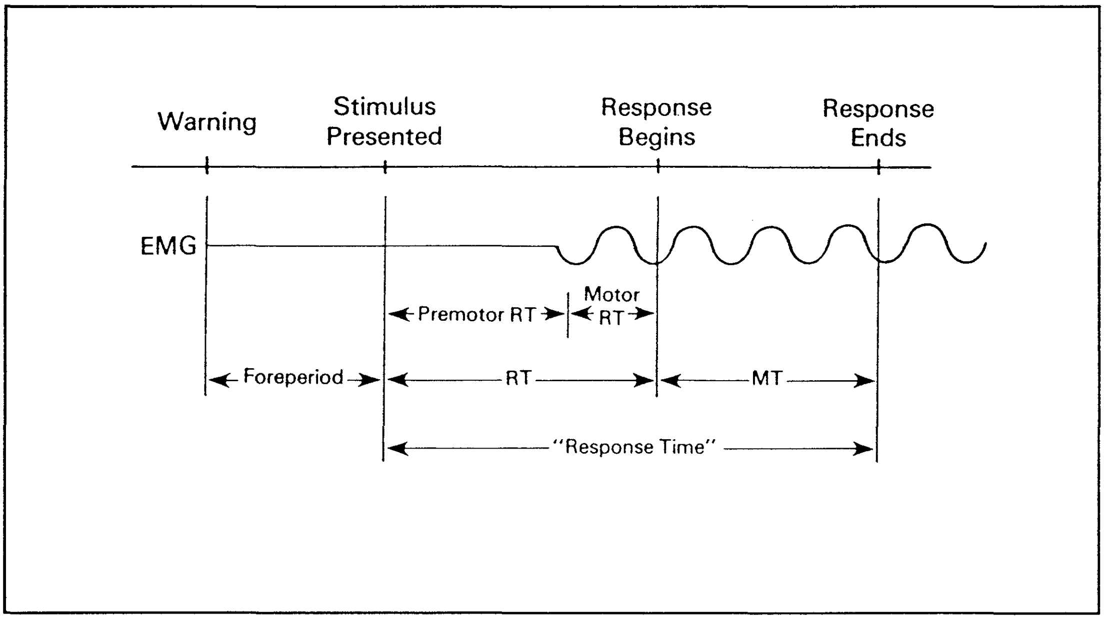

Figure 2.1 Critical motor events recorded in the reaction time (RT) paradigm (from Schmidt 1988b:65). The upper trace is a hypothetical representation of the electrical activity in the muscle relevant for the movement.

[9]As reproduced from Schmidt (1988b:65).

[10]Apparently, motor behaviour science under the motor systems approach is not particularly interested in the subject of perception. This, however, appears not to be the case for the action systems approach; definitions and discussions of perception and associated topics like sensation will thus be reserved for the relevant chapter, i.e. Section 4.2.8 in particular.

A question that often emerges in the study of movements when movement times decrease is that of the influence of the so-called *speed-accuracy trade-off*, which holds that (Schmidt 1988b:65)

> ... when performers attempt to do something more quickly, they typically do it less accurately. In most measures of speed, therefore, accuracy requirements are kept to a minimum so that speeding up the response (which is the major goal for the subject) does not seriously affect accuracy.

It is rather obvious that experiments requiring high speed but low accuracy would be of little significance for the field of piano technique, since speed and accuracy are inextricably intertwined in the performance of virtuoso passages.

2.2.2.3 Measures of response magnitude

The third way a skill can be measured is through determining the *response magnitude*; in the case of for instance, a javelin thrower, the response magnitude would be the distance the javelin has travelled. In the case of piano playing, a (rather crude) measure of the response magnitude could be the loudness produced by the individual keys struck by the performer.

According to Schmidt (1988b:66), response magnitude as a measure of skilled movement is, rather surprisingly, not used much in motor behaviour research, "... as the scientists apparently believe that skills are more easily assessed by measures of accuracy or speed".

2.2.2.4 Measuring speed and response magnitude in piano playing

In this section, an experimental setup is described which was employed by Shaffer (1981) for indirectly measuring various manifestations of speed and response magnitude in piano playing through detecting and coding the associated movements in the piano action. As a first step, Shaffer's (1981:343) succinct but exceptionally clear explanation of the functioning of the piano action is reproduced, *verbatim*, below:

> In the piano action, when a key is struck it raises a damper off its string and actuates a hammer, throwing it against the string and causing this to vibrate. The force of keystroke is translated into speed of hammer movement and thus into sound intensity. On the rebound the hammer is caught midway in its return trajectory; when the key is released the damper falls back onto the string, stopping the sound, and the hammer falls to its resting position. There are two foot pedals: pressing the left pedal displaces the keyboard action so that the hammers strike one less string on multistring notes, producing a quieter sound; pressing the right pedal lifts all the dampers off their strings, so that a note can be sustained when the key is released and other strings can vibrate in sympathy.

Using electronic transducers and a computer, Shaffer (1981:343) proceeded as follows to obtain and process information on the piano action as representative of the performance:

> The photocells were mounted in pairs, one pair for each of the 88 keys. These cells

detected the transits of a hammer shank in its up and down trajectories. They were placed to detect the (approximate) moment a key was struck, the moment the hammer hit the string, and the moment the key was released. Two microswitches detected the operation of the foot pedals. The signals from these sensors were amplified and coded into 12-bit words by a strobe circuit that fed them to a laboratory computer. All such words were assigned clock times to the nearest microsecond by the computer clock and stored on tape.

Following a performance the sequence of words was translated into a list, showing for each note played its time of onset (obtained from the upper cell), its time of offset (obtained from the lower cell), and the time difference between cells in the upward transit of the hammer. This listing was annotated by hand and returned to the computer, which then compiled a musically more interesting listing of the performance.

The new listing displayed the performance in successive bars of the music and separated the different voices. It listed for each note played its duration, the time between sounding that note and the next one in the same voice; its tonal quality of legato or staccato, measured by its temporal overlap, positive or negative, with the next note in its voice; and an index of its intensity, taken as the inverse of the upward transit time of the hammer. This index, monotonic with both the force of striking and the intensity of sound produced, was a consistent index of the former across all keys, but not of the latter across all notes, since this was a complex function of the acoustic properties of the piano and the room.

2.3 Information-processing theory and memory systems

Information is defined by Kerr (1982:309) as "the psychological concept of stimuli and cues. A stimulus can be almost any item present in the environment".[11] Defined more accurately from the engineering viewpoint concerned with information-processing, information can be described according to Schmidt (1988b:98,83) as

> ... [t]he content of a message that serves to reduce uncertainty. ... The amount of information transmitted is affected by both (a) the amount of uncertainty prior to the signal's being presented and (b) the amount of reduction of uncertainty.

For the purposes of the present study the first definition will suffice; thus it is not required to examine the statistical implications implicit to the second definition in greater detail.

Information theory, which is concerned "... with the balance between uncertainty and information" (Kerr 1982:37), is based mainly on developments in the field of communications engineering, in particular the work done by Shannon and Weaver in the late 1940's. About a decade later the first attempts were made to apply these concepts to the field of motor control.

Human movement in the environment can be studied from the perspective of man as a processor of the information that is available in the environment. It is postulated that the individual accepts

[11]The notion held by some ecological psychologists on what a stimulus is, is not quite this simple, as will be pointed out in Section 4.2.8.1.

information into storage systems called *memory*, that the information is subject to *processing* and that information is output to the environment in the form of movements (Schmidt 1988b:97). It is in fact possible to visualize a human as analogous to a so-called *black box* with input a signal from the environment and output a certain motor response. The events and processes that occur *within* the black box in particular are of interest for cognitive psychology. Knowledge of these processes "... is inferred from the overt behavior of the human under various experimental conditions" (Schmidt 1988b:75); direct investigations into the nature of the internal processes is not possible "... because the neural processes and their locations in the brain are not well understood" (Schmidt 1988b:76).

2.3.1 The stages of information-processing

Perhaps the most common method for inferring knowledge of human information-processing capabilities from observable motor behaviour is through observation of temporal aspects of the performance; in this regard the so-called *chronometric approach*

> ... makes heavy use of the reaction-time (RT) method, whereby the chief measure of the subject's behavior is the interval between the presentation of a stimulus and the beginning of the response (i.e., RT). (Schmidt 1988b:76)

Schmidt (1988b:77-78) gives the following typical interpretation of an everyday motor skill along the lines of the chronometric approach to the study of human information-processing:

> ... assume in driving a car that stimuli from the environment (vision of the road, horns honking) and from the driver's body (acceleration, vibrations) enter the information-processing system as input ... . As each stimulus is input, it is processed, leading to a response or not. Thus, the driver can be thought of as an information-processing channel,to which information is continually presented, and out of which comes responses.

Implicit in the above is the assumption that processes within the individual when driving a car - or throwing a ball and playing a succession of chords on the piano, for that matter - and performing a RT task are the same. Schmidt (1988b:78) warns that "... this assumption could be wrong, and many [authors] ... think that it is."

Following the work by Donders of 1868-1869, Schmidt (1988b:77) identifies three general stages of information-processing[12], namely

- stimulus-identification
- response-selection
- response-programming

All three stages of information-processing occur during RT.

[12]It is of course highly likely that each stage itself consists of various subsidiary stages.

In the following sections these stages of information-processing will be examined more closely.

2.3.1.1 The stimulus-identification stage

Stimuli impinge on the performer of motor skills through the sense organs. In piano playing, the classic example of stimuli presented to the performer is the printed music in front of him[13]. Bridges (1985:11) notes that in memorized music this visual information is stored in a transformed form as "... an aural, kinesthetic, and/or emotional concept". Probably of even more importance than visual stimuli in playing from memory at a stage when some fluency has been achieved are aural and kinesthetic stimuli[14], while the reverse situation may be the case when movements are learned from grassroots level, requiring for instance the wrist to be carefully watched in the study of arpeggio playing. In the present study, the stimulus-identification phase will be thought of as beginning with a stimulus in the environment that must be detected, i.e. the stimulus is starting the chain of events. This assumption is arbitrary, of course, since the stimulus could just as well be the result of the human interacting with the environment; in piano playing the stimulus, for instance a sound at a certain level of intensity, can be the result of a previous movement, but also be the stimulus for the next movement. Schmidt (1988b:97) depicts *stimulus-identification* as

> ... concerned with the reception of a stimulus, preliminary preconscious analyses of features, and extraction of patterns from the stimulus array. Variables like stimulus clarity and stimulus intensity affect the duration of processing in this stage.

Two components are associated with the stimulus-identification phase, namely *stimulus detection* and *pattern recognition.*

(a) Stimulus detection

When a stimulus acts on an individual, it must first of all be detected. The stimulus must be "... transformed into the code of neurological impulses headed towards the brain" (Schmidt 1988b:78), and it is assumed that the stimulus is further processed at various levels of analysis until it, as Schmidt puts it, "... *contacts memory*", arousing the proper association in memory. This association may be its name, its colour, or in the case of piano playing, for instance the relative intensity and/or pitch of an aural stimulus. The factors mentioned above in the description of the stimulus-identification stage that influence the temporal duration of the stage also effects the stimulus

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[13]It has been mentioned before that the present study is not aimed at an investigation of the complex processes involved in sight-reading; it is rather assumed that the note sequence is memorized already, and that the problem facing the learner is the physical execution of this note sequence.

[14]The manner in which these stimuli function as feedback in the learning process is examined more fully in Sections 3.2.1.1 and 3.2.1.2.

arousing the right association rather than the wrong association, or all possible associations.

(b) Pattern recognition

The need for pattern recognition arises from the fact that stimuli seldom occur in an isolated fashion; thus it becomes necessary to extract a pattern from the stimuli presented. The recognition of patterns can be either an inherited or learned ability; the former would for instance apply to verticality (Schmidt 1988b:78), while the latter would for instance pertain to recognize the movements required for fluent scale playing at the piano.

While the importance of analyzing patterns from static visual stimuli has been stressed by the Gestalt theorists[15], according to Schmidt (1988b:79), "... even more important for an understanding of motor behavior is an ability to extract patterns of movement from the environment". Patterns of the movements from one's own body can be inferred from how the environment changes from moment to moment, as well as from receptors in limbs, muscles, eyes and the inner ear (the latter functions with regard to balance). In fast-action sports, a judicious analysis of movement patterns can lead to an accurate prediction of what the opponent's next move will be (Schmidt 1988b:80).

As for piano playing, inferring information from the environment would be rather difficult, as the only changes that occur are the downward displacements of keys through relatively minute distances. Patterns learned through careful observation of one's own successful and less successful attempts, could however be of some use. Such observational activities are usually regarded, in the learning situation, as visual feedback; the use of visual feedback in the development of piano-technical skills will be examined more fully in Section 3.2.1.3. The advantages and limitations of observational learning, where the idea is to learn through studying *another* person's movement patterns, will be addressed in Section 5.2.2.2.

2.3.1.2 The response-selection stage

The information-processing stage of *response-selection* is described by Schmidt (1988b:97) as

> ... concerned with the translation or decision mechanisms that lead to the choice of response. The duration of this stage is sensitive to variables such as the number of stimulus-response alternatives and S-R compatibility (the extent to which the stimulus and response are "naturally" linked).

Of special interest for the duration of the response-selection stage is the number of movement

[15]See for example Bower and Hilgard (1981).

options available to the performer. An important parameter in this regard is the *choice reaction time*, or choice RT, which is defined by Schmidt (1988b:97) as the "RT for a task in which each response to be made is associated with a different stimulus".

It has been believed for over a century that information-processing involving the selection of a response from a number of alternative responses takes longer when the number of alternatives are larger (Schmidt 1988b:80), consequently leading to a longer time period for the actual response to take place; thus, "... if increasing the number of alternatives causes an increase in the choice RT, then the increased RT is associated with changes in the way the response-selection stage processed the information".

A relationship was discovered by Hick and Hyman in the early 1950's between the number of stimulus alternatives and choice RT; this relationship is referred to as Hick's law, or sometimes the Hick-Hyman law, for example Kerr (1982:220). This law, expressed in mathematical terms, states that (Schmidt 1988b:98) "... the choice RT is linearly related to the Log_2 of the number of stimulus-response alternatives, or to the amount of information that must be processed in order to respond".[16] Thus a particularly attractive interpretation, due to its simplicity, of Hick's law is that the time necessary for deciding on a response is linearly proportional to the "... amount of information that must be processed in coming to that decision" (Schmidt 1988b:82). It is however possible that the validity of this law under particular circumstances can be affected by "... high stimulus-response compatibility, extensive practice, or repeated responses" (Kerr 1982:255).

2.3.1.3 The response-programming stage

Schmidt (1988b:97) defines *response-programming*, the final stage in the series of three stages that comprise information-processing, as concerned with preparing the movement decided upon, or "... changing the abstract idea of a response into muscular action. The duration of this stage is related to variables affecting the response, such as response complexity and response duration". The complex series of events that occur in the response-programming stage is postulated by Schmidt (1988b:89) as the recall of some "program of action" from the memory of the performer, preparation of the program to get started, preparing relevant subsystems of the motor system for execution of the program, and initiation of the movement. The subject of motor programming will be addressed in Section 2.8.

[16] $\text{Log}_2(N)$ is the power to which the base 2 must be raised to achieve N.

2.3.2 Memory systems

Schmidt (1988b:91), following an analogy with computer memory systems, points out three conceptual structures that hold information for future processing, namely

- short-term sensory store (STSS)
- short-term memory (STM)
- long-term memory (LTM)

Adams (1987:64), however, points out that while the differentiation between short-term and long-term memory systems was viable for verbal retention and researchers hoped that motor retention[17] could be described in the same way, it became clear by the 1970's

> ... that the conceptual distinction between short- and long-term memory had little to offer an understanding of motor behavior. Research on motor retention became more of an empirical undertaking, with efforts aimed mostly at short-term motor retention ...

For the present discussion on motor *control*, and in view of Adams's notion on the validity of a conceptual division into types of motor memory, it is sufficient to consider here for the sake of completeness merely brief descriptions of the three conceptual structures for motor memory. Some additional remarks on STM and LTM will be made in the part of the present study dealing with motor learning as viewed from the motor systems perspective, i.e. in Section 3.5 in particular.

Schmidt (1988b:98) defines the *short-term sensory store* (STSS) as "[a] functionally limitless memory store for holding literal information for only about 1 sec". STSS is thought to be the memory level nearest to the environment, accepting information presented by the environment and losing it again as soon as new information presents itself. *Short-term memory* (STM), which is usually closely associated with consciousness[18], is described by Schmidt as "[a] memory store with a capacity of about seven elements, capable of holding moderately abstract information for up to 30 sec." STM is regarded as storage system for information from either STSS or LTM; evidence was found by Miller (1956) that verbal STM has a capacity of only seven plus or minus two items or chunks; the latter being larger, recognizable collections for smaller items, for instance words[19]. In some unknown way, information is transferred from STM to *long-term memory* (LTM), which can be described as "[a] functionally limitless memory store for abstractly coded information, facts, concepts, and relationships; presumably storage for movement programs".

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[17]*Motor retention* will be defined in more formal terms in Section 3.5.

[18]The problems surrounding the concept of consciousness will be remarked upon briefly in Section 2.4.

[19]The concept of chunking is discussed with respect to piano sight-reading by Fourie (1990), and with respect to facilitating the execution of technically difficult passages by Jacobs (1990).

2.4 Attention

2.4.1 The concepts of attention and interference

Although an active interest has been maintained for many years by psychologists and motor behaviour researchers regarding the subject of attention, it is still not clear how attention should be defined. While motor behaviour science is not concerned with addressing the role of the conscious mind in motor activity in particular[20] (Bridges 1985:15), attention has in the past been closely associated with the concept of *consciousness*, or (Schmidt 1988b:139) "[t]he mechanism or process by which humans are aware of sensations, elements in memory, or internal events". Common sense views of consciousness have contended that it controls what humans perceive and how they act; it has however been extremely difficult to attempt verification of these and other views because

> ... the only way to understand what was "in" subjects' consciousness was to ask them to *introspect*, or "search their own minds", which is acknowledged to be prone to errors or biases related to situational variables and expectations.[21] (Schmidt 1988b:100)

Schmidt (1988b:100), however, declares that the relationship between attention and consciousness is of a rather superficial nature and thus does not warrant further exploration; the focus should rather be aimed in terms of the human's limited capacity for handling information from the environment or from long-term memory. While some theorists think of attention as a single limited capacity for information-processing, others hold the view that attention

> ... is really a number of pools of capacity for separate kinds of processing. The capabilities to perform various tasks together is presumably limited by these capacities; therefore, attention demand is usually estimated indirectly by the extent to which tasks interfere with each other. (Schmidt 1988b:138)

The phenomenon of interference among tasks, is of considerable importance both for attention and learning, or "automatization", of motor tasks. Schmidt (1988b:101,139) distinguishes between *structural interference* and *capacity interference*; the former is "[i]nterference among tasks caused by the simultaneous use of the same receptors, effectors, or processing systems", while the latter can be described as "[i]nterference between tasks caused by limitations in attention". An example of

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[20] An approach that is followed in the present study as well, noting its motor behaviour emphasis. A possible foundation for attacking this problem could be found in the so-called psychologies of consciousness, which is explored by Bridges (1985).

[21] In view of this uncertainty about what consciousness actually is, it is not clear on what grounds Bridges (1985) identifies a boundary between the conscious and unconscious - or "Province of Automaticity" as he describes it using Matthay's terminology (Bridges 1985:34) - in piano playing. This boundary plays a major role in the various "implicit psychologies of technique" identified by him in the methods of *inter alia* Matthay, Gát, and Whiteside, as can be easily seen in his information-processing flowchart representations of each method (Bridges 1985:36,47,62).

structural interference is writing and dialling the telephone with the same hand because the hand can only be in one place at a time.

Interference can serve as an indication of whether a task requires attention as follows (Schmidt 1988b:100): if two tasks can be performed as well at the same time as when each is performed on its own, one of the tasks is said to be performed "automatically", thus not demanding part of the limited capacity for attention. If, however, a certain task is performed less well when carried out simultaneously with another, both tasks are regarded as demanding of attention[22].

In the following sections the main trends regarding favoured theories of attention will be pointed out briefly. Also, important issues on interference with the stages of information-processing and execution of motor responses following processing will be argued.

2.4.2 Theories of attention

In order to be able to form a proper understanding of the various theories of attention, it is necessary to distinguish between the concepts of *serial processing* and *parallel processing*. *Serial processing* is defined by Schmidt (1988b:98) as "[a] style of information processing in which stages of processing are arranged sequentially in time", as opposed to which *parallel processing* can be considered "[a] type of information processing in which at least two processes can occur simultaneously".

The earlier *fixed-capacity* theories held that (Schmidt 1988b:102) "... attention was a *fixed* capacity for processing information and that performance would deteriorate if this capacity was approached or exceeded by the task requirements". Implicit to some of these theories was the assumption of a filter which was located at some stage of the information-processing mechanism; prior to reaching the filter many stimuli could be processed in parallel, thus not requiring attention. The filter then "filtered out" all but one of these stimuli, which was subsequently subjected to attention-demanding "single channel" processing.

Recently, however, the view that attention should be conceived of as "... a *set of pools* of resources" has gained some predominance; such a view makes it possible to explain the fact that it is possible to move for instance the middle finger of both the left and right hand at the same time. Of some importance for piano playing is the notion that it is possible to devote attention to different stages of information-processing at the same point in time; Schmidt (1988b:104) cites complex motor

[22]It is also possible to determine by physiological measurement whether a person "pays attention" - certain changes in skin resistance and pupil diameter, for instance, are usually indications of mental effort, which in turn is associated with "paying attention" (Schmidt 1988b:101).

tasks such as typing and music sight-reading "... for which attention is thought to be devoted to input (sight reading) and output (finger movement) stages at the same time" as representative examples.

2.4.3 Attention and interference during and after information-processing

2.4.3.1 Interference in the stages of stimulus-identification and response-selection

In the *stimulus-identification stage* of information-processing, processing apparently is accomplished *in parallel* without interference; this is, however, not the case in the *response-selection* stage.

For the purpose of substantiating this statement, Schmidt (1988b:105-106) directs attention to the so-called Stroop phenomenon, named after its Dutch investigator. In an experiment concerned with this phenomenon conducted by Keele (1972), subjects were asked to respond to four different colours by pressing appropriate buttons. These colours were presented either by using irrelevant symbols such as $\pm$, or by printing a specific colour in letters spelling the name of a different colour, for example printing the word *RED* in blue ink. The interesting outcome was that RT for the latter condition was slower than in the first case, even though only the *colour* of the symbol was the relevant stimulus. This phenomenon can probably be accounted for as follows: because the subject has to choose between pressing the "red" button due to the verbal cue implied and the "blue" button because of the colour cue, interference occurs in the response-selection stage of processing. Regarding the stimulus-identification stage, Schmidt (1988b:106) observes the following:

> ... the fact that both stimuli (the color and the word) achieved *memory contact* approximately together implies that the processing of the two patterns in stages prior to response selection must have been simultaneous ... [suggesting] that the processing in stimulus identification occurs in parallel and without attention.

Also of interest to attention and the stimulus-identification stage is the so-called *cocktail party problem*, which is concerned with a person's ability to concentrate on one stimulus within an environment packed with various other stimuli. The nomenclature of this problem is derived from the ability of a person attending a party to engage in conversation with one other person amidst many other conversing people and the general tumult of the party. Furthermore, in spite of the fact that a conscious effort is made to ignore all other stimuli, certain messages always seem to get through, for example hearing one's name spoken. According to Schmidt (1988b:106), the idea of *selective attention* provides a possible explanation for this phenomenon:

> [i]t is as if stimuli from the environment had entered the system simultaneously and had been

> processed [in parallel] to some superficial levels of analysis, with only those relevant (or pertinent) to the individual being processed further. ... this further processing will usually require attention ... implying that two such activities cannot be done together without interference.

2.4.3.2 Interference and the response-production stage

It has been pointed out earlier that information-processing in its initial phases is principally a parallel event. Schmidt (1988b:109) states that the response-production stage[23], where movements are organized and initiated, "appears to be distinctly different in character. Research studies from various sources point independently to the view that only one movement can be initiated at a time".

The main supporting experimental evidence accounting for the fact that some sort of "bottleneck", or single channel, exists in the response-programming stage, comes from the so-called *double-stimulation paradigm*, in which the subject must react to two closely spaced signals addressing different modalities (e.g., visual and aural) requiring different responses[24]. Investigations of this paradigm revealed that the second of the two closely-spaced responses usually suffered considerably in processing speed, i.e. taking longer to occur in the presence than in the absence of the first stimulus.

Subsequently, a phenomenon termed *psychological refractoriness* was recognized - "... the delay in responding to the second of two closely spaced stimuli" (Schmidt 1988b:139). The practical consequences of psychological refractoriness for motor behaviour can be argued as follows (Schmidt 1988b:138):

> It requires that movements be produced in *discrete bursts* even though the stimuli calling for them are presented continuously. *Interference among two-handed movements, even if planned in advance, is massive if their underlying temporal structures are not similar, suggesting that only one movement at a time can be controlled by a response-execution stage subsequent to RT.* [Italics added]

Schmidt (1988b:112) does point out, however, that some empirical evidence exists which contradicts the hypothesis of a single-channel to account for psychological refractoriness.

Various factors have been found to diminish the delay in RT for the second of the two closely-spaced stimuli associated with psychological refractoriness. Practice has been found to decrease this delay but not eliminating it; thus

> ... suggesting that refractoriness might have a "real" structural basis in the information processing system. (Schmidt 1988b:113)

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[23]I.e., response-programming stage.

[24]This paradigm is described in greater detail by Schmidt (1988b:109-110).

Stimulus-response (S-R) compatibility, or the degree to which the stimulus and the required response relate to each other, also plays a role; if the compatibility among the stimuli and responses is very high, delays in reaction times can be reduced.

Some noteworthy practical examples of psychological refractoriness, as viewed from the double-stimulation paradigm context, can be traced to certain ball games; Schmidt (1988b:114) cites the example of a player faking an opponent by moving slightly to the right - thus suggesting a fulfledged movement to the right - but then in fact carrying the "real" movement to the left. If his opponent follows the first movement, "... it will require a full RT ... *plus* the added delay caused by refractoriness to *begin* to respond to the second movement", ensuring that his opponent will be too late to counter the "real" movement to the left.

Finally, some attention should be directed to Schmidt's (1988b:114-115) suggestion, based on findings by *inter alia* Kahneman (1973:162 ff.), that "... no matter how small the interval between stimuli - provided they are not grouped and emitted simultaneously - approximately 200 msec occurs between responses". A question, however, immediately arises on the validity of such a statement for piano playing, where it is not uncommon to find time intervals between notes of far less than one fifth of a second (for example in fast scale playing); Schmidt (1988b:115) clarifies this issue as follows:

> The "response" that is planned by the response-programming stage is still one response, but it has many parts that are not called up separately. This can be thought of as *output chunking*, whereby many subelements are collected into a single unit, called a *motor program*... . Also ... these programmed outputs occur in discrete "bursts" separated by at least 200 msec. These discrete elements are difficult to view directly, however, because the muscles and limbs smooth out the transitions between elements, giving the impression that we respond continuously.

2.4.3.3 Attention and interference during movements following information-processing

According to Schmidt (1988b:116), it is possible to identify a conceptual "stage" of information-processing beyond the three stages of information-processing discussed earlier; this stage is associated with that period in time "... in which the individual carries out the movement and keeps it under control".

Schmidt (1988b:117) points out that care should be taken in identifying the focus of awareness during skilled motor behaviour: is it the movement *per se* that requires awareness, the environment, or the programming and initiation of future movements?

It nevertheless appears rather obvious that, while the bulk of attention is devoted to any particular component of the movement process, other components have to be executed more or less "automatically". The usual description of tasks performed "automatically" is that these tasks

> ... can be performed without interference from other mental tasks involving (conscious) information processing activities. This fits in with our subjective experiences about "automatic" movements which are done without consciousness. (Schmidt 1988b:119)

It is worthwhile to clarify at this stage precisely what is meant by the adjective *automatic*; according to Schmidt (1988b:108), "... if a process is to be truly automatic, then *any* other simultaneous task should be possible without interference". However, it can been argued that no information-processing activity seems to occur in an entirely interference free manner; Schmidt (1988b:119) therefore emphasizes that "... it is probably best to think of automaticity *with respect to* some other simultaneous secondary task(s)".

Sometimes the RT for a secondary task which is executed simultaneously with a primary task is not higher than when it would have been executed in isolation, indicating that interference does not occur between the two tasks. This fact, however, cannot be taken *per se* to indicate that the primary task is indeed carried out automatically[25]; it merely shows that "... the particular processes needed in *this* ... [secondary movement] task are not also involved in *that* [primary] movement task" (Schmidt 1988b:119).

Of particular interest for the present study is the interference among hand movements which are planned in advance and have to be executed simultaneously. This particular class of movements is characterized by the absence of any obvious environmental stimulus; thus the subject of interference should rather be approached from the viewpoint of control of the relevant limb itself. Schmidt (1988b:120) cites from the field of piano playing the simultaneous execution of different metres in each hand and the playing of *rubato* proper - "... the gradual speeding or slowing of one hand with respect to the other" - as particularly difficult examples. In experiments from motor behaviour science which involved somewhat easier tasks, in which subjects were only required to tap simultaneously different rhythms with each hand, subjects found the said tasks very difficult. According to Schmidt, the motor systems theory interpretation of these findings is generally in terms of motor programs[26];

> ... it is argued that movements are organized with a powerful underlying temporal structure ... [I]t is assumed that only one such temporal structure can be organized and executed at a time, so two tasks with different temporal structures cannot be performed together without massive interference. As a consequence, the motor system appears to "prefer" a mode in which the hands are strongly coupled in time ...

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[25]The so-called *probe technique* experiments from which this conclusion was obtained is overviewed by Schmidt (1988b:118-119).

[26]It is also possible to explain this problem by considering the response-execution "stage" as a single-channel device, requiring for the performance of dual-tasks the same underlying temporal structure.

A somewhat more subtle occurrence of a similar problem in piano playing occurs in the dynamic shaping of separate voices of contrapuntal compositions, for instance the Bach *Fugues* from *Das Wohltemperirte Klavier*. While the meter in both hands obviously remains the same, the "meter" on a "macro level", i.e. the phrase structure, in general does not correspond for all the voices, except at cadence points; one voice, for example, might enter while another is already halfway through its current phrase. Thus, in a typical four-voiced fugue, where each hand will usually be required to handle two voices, a considerable challenge is posed to the pianist with respect to the simultaneous control of the unique characteristics of each individual voice.

2.4.3.4 Automatic and controlled processing

The essence of the two types of information-processing referred to as *controlled processing* and *automatic processing*, as advocated by Shiffrin and Schneider (1977) for perceptual learning, is conveniently summed up by Schmidt (1988b:107) as follows: controlled processing is

> ... (a) slow; (b) attention demanding, in that other similar tasks interfere with it; (c) serial in nature; and (d) strongly "volitional," in that it can be easily stopped or avoided altogether

while automatic processing is

> ... (a) fast; (b) not attention demanding, in that other operations do not interfere with it; (c) parallel in nature, with various operations occuring together; and (d) not "volitional," in that processing is often unavoidable.

Adams (1987:65) points out that psychologists have believed since 1890 - "without much evidence", though - in the shifting of attention with practice from controlled processing to automatic processing for motor behaviour. However, in spite of various studies and discussions on the topic, there is as yet "... no evidence of a shift from controlled to automatic processing for motor behavior ..." (Adams 1987:66).

In view of the above, this topic will therefore not be pursued any further here.

2.5 Anticipation

In the discussion of motor control so far, it was implicitly assumed that all stimuli are presented in the context of an experimental reaction time paradigm to an unexpectant subject. Therefore, no anticipation by the subject of the stimuli was provided for; a rather unnatural approach when trying to investigate everyday skilled human behaviour, for which "... suddenly presented and unexpected stimuli are the exception rather than the rule" (Schmidt 1988b:122).

It is possible to distinguish between three different types of anticipation:

- receptor anticipation
- effector anticipation
- perceptual anticipation

Kerr (1982:312,307,311) defines these types as follows: *Receptor anticipation* is anticipation "... in which the performer must also assess the duration of certain external events". *Effector anticipation* is anticipation "... in which the performer must predict the time it will take to perform a movement", while *perceptual anticipation* involves "... the performer ... [identifying] some regularity in the approaching event based only on past experience".

In subsequent sections the consequences of a performer's capability to anticipate in a spatial - or event - sense, and a temporal sense will be investigated.

2.5.1 Spatial, or event, anticipation

Schmidt (1988b:139) describes *spatial, or event, anticipation* as "[t]he anticipation of which stimulus (or the response to it) will occur". When a subject receives information about the nature of a movement in advance, some of the information-processing that is usually confined to reaction time can be done in advance, effecting a decrease in RT when the actual stimulus arrives. When enough information is supplied beforehand, it is even possible to circumvent the entire response-selection stage, especially because one response can be selected and planned while another is being executed (Schmidt 1988b:123-124).

2.5.2 Temporal anticipation and the preparation phase in voluntary motor control

While only a "rather modest" shortening of RT can be obtained through spatial anticipation (Schmidt 1988b:124), experimental investigation into *temporal anticipation* has suggested that "... if the person can anticipate *when* the stimulus is going to arrive, rather large reductions in RT can be made. Under the proper circumstances, the performer can eliminate RT altogether".

The *foreperiod*, in a simple RT test, is the period in time from a warning signal up to the actual onset of the stimulus. For the sake of completeness, some of the effects of varying foreperiod (Schmidt 1988b:124-126) are briefly noted here. For foreperiods of less than a few seconds which occur regularly, with all aspects of the required response being known beforehand, the subject can, after some practice, respond essentially simultaneously with the stimulus. This is however not the case when the foreperiod is long, "... because the subject cannot anticipate the *exact* arrival time when it is so far in the future".

Essentially equivalent to the foreperiod in an RT test is Kerr's (1982:255) notion of the *preparation phase* in the voluntary execution of a motor task. A simple example from athletics of the events bordering a preparation phase, can be found in the case of a runner preparing to take off; the "set" instruction given by the starter represents the warning signal, while the pistol shot is the actual stimulus for the start-off. Two subsidiary factors of interest for the preparation phase are termed the sensory set and motor set respectively.

Kerr (1982:217) defines the *sensory set* as

> ... a change in the level of alertness such that the subject increases the rate at which target signals can be processed. This change occurs within the central processing mechanism and not peripherally at the level of the receptor.

Of particular interest is the fact that this increased alertness is not modality-specific; being alert in the expectation of a visual stimulus will also produce a fast RT for an unexpected auditory signal. Also, signals do not have to be as strong as anticipated to trigger the required response: "[n]ot all signals or cues are as obvious as a starting gun. Conceivably, as a spectator in the crowd one could cause a false start by snapping one's fingers before the gun goes off" (Kerr 1982:217).

According to Kerr (1982:310), the term *motor set* in the preparation phase is associated with the selection of the most probable movement under the particular circumstances from the host of movements that is likely to occur.

At the present stage it is not clear how knowledge of the sensory set and motor set can benefit the learner of piano playing.

2.5.3 Benefits and costs of anticipation

Succinctly stated, the benefits of correctly anticipating a movement lies in the short RT for accomplishing the response. On the other hand, if a response is incorrectly anticipated, the "cost" of this error is the time lost in inhibiting the incorrect movement and starting anew with the right motor response. In some competitive ball games, the latter factor could be crucial in determining the outcome of the match; the example of time lost due to incorrect anticipation in a game of football has already been referred to in Section 2.4.3.2. An example of detrimental anticipation in piano playing can be found in the performer who, in anticipating, for example, a difficult octave passage a few measures away, prematurely fixes his hand into "octave position"[27], rendering it unfit for the task immediately at hand, namely rapid arpeggio playing (for example), which requires a rather supple hand and fingers.

2.6 The influence of stress and arousal on attention

The subject of performance anxiety under musicians in general - and pianists in particular - has been the subject of considerable interest for quite some time, as attested by the writings of for example Reubart (1985), Lehrer (1987), and Louw (1988). In a great many of the books on piano technique written by musicians, a chapter or two is usually devoted to the problem of "nerves" when performing in public, for example Harrison (1953), Merrick (1958), and Sandor (1981)[28]. According to Neuhaus (1973:88), confidence forms the basis for all freedom in piano technique, and as such should be the foremost goal to strive for. Many problems that seem to relate to the physical apparatus involved in piano playing, such as superfluous movement and stiffness, can in fact be seen as "signs of insecurity with its unpleasant consequences".

While the present study is by no means intended to attempt a treatment of performance anxiety, it is nevertheless worthwhile to investigate - from a motor behavioural point of view - the question as phrased by Schmidt (1988b:130) of "[w]hat effect ... stress and panic have on information processing in these situations that causes people to abandon highly practiced techniques and resort to the skill level of an inexperienced beginner ...".

The terms *arousal* and *activation* can be thought of as representative of the amount of effort exerted by an individual to whatever task he is assigned; these similar states can respectively be defined (Schmidt 1988b:139) as "[a]n internal state of alertness or excitement ..." (arousal), and "[a]n internal state characterized by potential action ..." (activation). Unlike arousal and activation, the concepts of *stress* and *motivation* can not be thought of as "neutral" terms; *stress* is defined by Schmidt (1988b:139) as "[a] *negative* emotional state that tends to direct the individual away from some particular situation [italics added]", while *motivation* can be described as "[a]n internal state that tends to direct the system toward a goal".

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[27]Described in Section 4.2.6.

[28]Already as early as the 1940's more than a superficial interest was maintained in this topic, as can be deduced from the relevant chapter in Ching (1946), which is entitled "Freudian psychology and the pianistic art".

The relationship between the amount of arousal and motivation has been shown not to be a simple one; instead, the quality of performance varies like an inverted U with arousal as independent variable, which implies that an optimal level of arousal exists, contrary to

> [t]he common belief ... that the more "up" we are, the better we perform. (Schmidt 1988b:132)

As a representative example of the influence of arousal and stress on information-processing, the idea of *perceptual narrowing* is treated here. Increased arousal brings about the narrowing of the attentional focus, resulting in the exclusion of input of stimuli which are relatively improbable. There is also an increase in the "... number of shifts in attention to different input sources" (Schmidt 1988b:133), a phenomenon referred to as *distractibility* -

> ... high levels of arousal are likely to cause the individual to direct attention to many different sources from moment to moment, with some of these sources providing irrelevant information and causing the relevant signals to be missed.

Perceptual narrowing therefore implies that the individual's ability to discriminate between relevant and irrelevant stimuli deteriorates. In extreme cases of increased distractibility, hypervigilance (panic) could result; this term refers to situations in which completely inappropriate actions are taken, due to the fact that not one of the many alternatives that are considered, are considered long enough for the selection of a proper action.

According to Schmidt (1988b:135), tasks that may benefit most from high levels of arousal are "... very simple ... with but a single or a few signal sources and relatively stereotyped responses"; these types of tasks obviously do not include most instances of piano playing, indicating that, for the latter,

> ... telling people to "try harder" does not necessarily lead to gains in skill, and may actually do the reverse. (Schmidt 1988b:136)

2.7 Cybernetics

The theory of cybernetics, which was introduced by Wiener in the post-World War II years, employs the analogy of man as a complex machine; while a computer has systems for input, output, storage and control, a person receives and responds to stimuli, with control and storage provided by the brain. Kerr (1982:37) describes cybernetics in more specific terms as "... a type of closed-loop system in which, characteristically, there is a direct link between output and input based on continual feedback ...".

Of prime importance for the field of cybernetics are the control engineering concepts of the *closed-loop system*, *open-loop system*, *feedback*, and *feedforward control*. The highly complex human motor system should be considered as some sort of "hybrid" of closed-loop and open-loop systems (Schmidt 1988b:183).

In order to obtain some insight into the workings of these systems, the closed-loop system, open-loop system and feedback will as a first step be briefly explained in terms of examples from everyday life. Formal descriptions will then be given of the closed-loop system, the open-loop system and feedforward control, with applications to piano playing in the case of the closed-loop system and feedforward control. The subject of feedback will be given a detailed treatment in Section 3.2.

2.7.1 Some concepts from control system theory explained

A closed-loop system can be distinguished from an open-loop system in that the former has feedback from the system response. Thus error detection and error correction are possible for the closed-loop system, while this is not the case for the open-loop system. Examples of an open-loop system and a closed-loop system from everyday life are, respectively, a woodburning stove and an automatic heater (Adams 1987:58). For the wood-burning stove, the heat output simply depends on the amount of wood that is supplied to keep the fire burning - there is no sensing by the stove itself of the degree of heat output or any subsequent adjustment of the fire to compensate for too much or too little heat. The automatic heater, on the other hand, uses the thermostat setting as a reference for comparison with the actual heat output. If there is a difference between the two quantities under comparison, which can be considered the error, the heater will turn on and off until the discrepancy is eliminated.

2.7.2 Closed-loop system

Schmidt (1988b:184) defines a closed-loop system - which can also be referred to as a servomechanism or servo - as "[a] control system employing feedback, a reference of correctness, a computation of error, and subsequent correction in order to maintain a desired state ...".

In Figure 2.2 the basic elements of the closed-loop system of control is displayed diagrammatically. A closed-loop system typically consists of three parts. Input about the goal to be achieved by the system is supplied to a *reference mechanism*. Next, the reference mechanism "... samples the environment that it is attempting to control" (Schmidt 1988b:142) to determine what the current state is with respect to the goal that was set; this information is called feedback. The reference mechanism proceeds to compare "... the value of the goal to the value from the environment"; this difference between the desired and actual states is termed the *error*. The *executive level* uses this error information to decide how it can be reduced to its smallest possible value; if the error is not at that value yet, the *effector level* is activated, which causes some mechanism to adjust the environment. The new environmental information is fed back again to the reference mechanism, where a new error is determined, and so forth. The process continues until the error is sufficiently small, whereupon the executive level terminates the activities of the system.

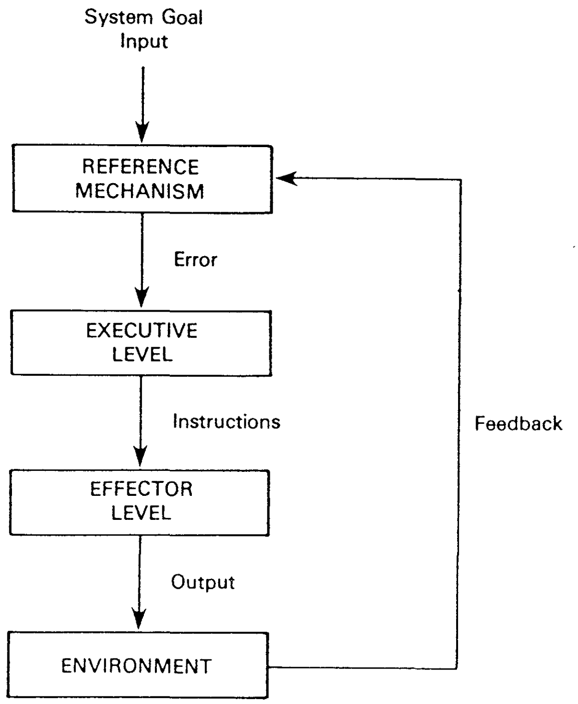

Figure 2.2 Flow diagram showing the basic elements of a closed-loop system of control (from Schmidt 1988b:142).

In the context of the human motor system, the reference of correctness and the executive level of the closed-loop system could be seen as contained in the stages of information-processing, so that feedback would be picked up through the short-term sensory store (STSS) and the stimulus-identification stage (Schmidt 1988b:143). Feedback is received in the form of information from the various muscle, joint and tendon receptors as well as from the visual and aural facilities. The executive level would be considered as part of the response-selection and response-programming stages, while the effector level would actually be the muscles used to effect changes in the environment decided on by the executive level.

At this stage it is appropriate to introduce here a possible representation of piano playing by a closed-loop control system. Although Bridges (1985:9-10) only by implication indicates the presence of a mechanism of reference (which is of critical importance for any closed-loop system), it is nevertheless worthwhile to reproduce here as Figure 2.3 his closed-loop representation of unmemorized piano playing, from which one presumably "... can see at a glance all the facets of piano performance that need to be addressed to have a complete understanding of the pianist's skill"[29].

Apparently, Bridges's perceptual mechanism relates to the stimulus-identification stage of information-processing, and his decision mechanism to the response-selection stage. The response-programming stage also seems to be incorporated into his decision mechanism. The effector level identified in Schmidt's representation of the closed-loop system, is accounted for by Bridges' executive mechanism, while proprioceptive information and external results perceived by the other sense organs are fed back "... into the sensory part of the perceptual mechanism"[30] (Bridges 1985:9) in order to evaluate or modify the ongoing motor response.

According to Bridges, the three main components of the control system are constantly exchanging information with memory. Although Bridges does seem to make an implicit distinction between visual memory and motor memory, his depiction of the nature of the latter appears to be rather vague, i.e. it is not clear whether he means, for example, short-term memory, long-term memory, or short-term sensory store[31].

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[29]Unfortunately, it is not clear from which sources in the field of psychology Bridges derived this representation.

[30]Due to the lack of formal definition of concepts which persists throughout Bridges' (1985) thesis, it is not clear what - if any - other parts the perceptual system might have, and how the "sensory" part fits into the whole.

[31]These concepts were treated in Section 2.3.2.

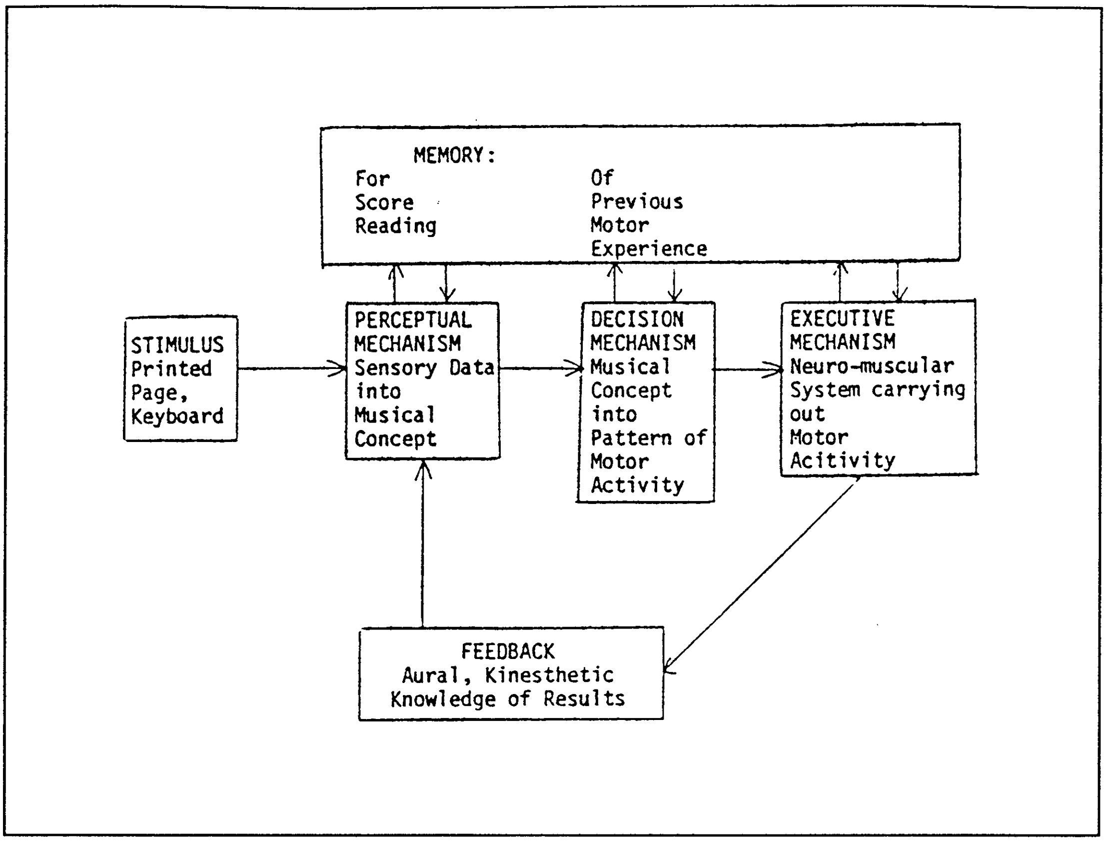

Figure 2.3 A flow chart representation of the facets of piano performance from a score as they function in a closed-loop model (Bridges (1985:10).

Finally, some mention should be made of the concept of *reflexive closed-loop control.* Schmidt (1988b:183) emphasizes that the greatest strength of closed-loop theories lies in their explanation of slow movements, or movements that have high accuracy requirements; closed-loop theories in fact have difficulty in explaining the nature of error corrections as they occur in fast movements. Evidence has however been found for the existence of reflexive closed-loop control, which is based on the premise that the central nervous system contains closed-loop mechanisms that do not require any attention. Reflexive closed-loop control thus differs radically from the conscious information-processing models for control that were discussed earlier. Schmidt (1988b:165) cites an experiment performed by Dewhurst as representative of the manifestation of reflexive control in quite a number of studies: a subject was required to hold a weight in one hand with the elbow kept at a certain angle. Unexpectedly for the subject, the mass of this weight was suddenly increased, and the hand began to move downward, this movement representing an "error" in performance. The brevity of the time period that the hand took to move back to its original position, i.e. correcting the error, suggested that this movement could not have been initiated by an attentionally-based control system of the type discussed earlier; it is rather believed now that control is effected by reflexes in the lower levels of the central nervous system.

Due to the fact that reflexive closed-loop control is an area of study entailing investigation at mainly the neurophysiological level of analysis, more extensive discussion of the subject falls beyond the scope of the present thesis.

2.7.3 Open-loop system

According to Schmidt (1988b:184), an open-loop system can be defined as "[a] control system with preprogrammed instructions to an effector that does not use feedback information and error-detection processes". The concept of an open-loop system is closely related to that of the motor program, which will be discussed in Section 2.8.

2.7.4 Feedforward control

Feedforward control is described by Schmidt (1988b:184) as "[t]he sending of information ahead in time to ready a part of the system for incoming sensory feedback or for a future motor command". Feedforward control is closely related to the subject of anticipation; it therefore can either ready the muscles of the effector level for forthcoming instructions for movement, or, according to Schmidt (1988b:146)

> ... ready ... reference systems to "expect" a certain signal.

Schnabel (Wolff 1972:20) in his teachings suggested a type of control during piano playing which apparently integrated feedforward with feedback control: "... the performer's inner ear hears everything twice: each little bit is mentally anticipated as well as checked out by later control. If all goes well, these two mental perceptions are blended into one ...". Another pedagogue who apparently advocated the use of feedforward control is Bardas, who used the term *innervation* "... to refer to the imagining at the appropriate fraction of a second before, the exact, most comfortable muscular movement needed to effect the sound that is sought" (Songayllo 1987:62).

Schmidt (1988b:147) notes that feedforward control is especially important for the control of movement in the central nervous system. As investigations of a neurophysiological nature fall beyond the scope of the present study, this theme will not be subjected to closer scrutiny here.

2.8 Motor programs

2.8.1 Definition and functions

Adams (1987:60), in correspondence with Shaffer (1980:443), defines a motor program as "... an abstract structure in memory that is prepared in advance of the movement ... [containing] the patterns of muscle contractions and relaxations that define movement". The implication of the motor programming concept is that movements are driven centrally; substantial parts of movement sequences can thus be executed without requiring the assistance of response-produced feedback.

Of particular importance for piano playing as a skill consisting of sophisticated, fluent movements, is the contention by Shaffer (1980:443) that three basic functions can be attributed to a motor program, namely

> [f]irst, that it can confer fluency on a movement sequence so that the sequence unfolds at a fast rate, achieving its goals accurately and with an economy of movement. Second, it can confer expressiveness, so that the sequence acquires definite rhythms of timing and intensity, and in dancing or gymnastics it may take on a quality of gracefulness. Third, it has a generative flexibility and so can produce a performance appropriate to its context for an indefinitely large variety of contexts.

The properties associated with these functions will be manifest only in highly skilled performance, whereas unskilled performance may only hint at some of these properties -

> [t]hus, if our aim is to understand the mechanisms of motor programming this is best served by studying skilled performance, observing and interpreting unskilled performance as approximations to, or simpler forms of, this. (Shaffer 1980:444)

2.8.2 Evidence for the existence of motor programs

According to Schmidt (1988b:227), essentially three lines of evidence exist that support the notion of motor programs.

The *first* is the fact that feedback is inherently a slow process, so that movements which are rapid enough will be executed before information can be fed back to the stage of information-processing concerned with detection and correction of errors.

The *second* line of evidence holds that some movements appear to be planned in advance; this is rather clearly suggested by the fact that reaction time increases as the complexity of the movement pattern increases, which in turn indicates an increase in the time required for the response-programming stage. Elaborate and sophisticated movement sequences have to be preprogrammed for these increased reaction times not to disrupt the continuity of action.

Thirdly, the idea of motor programming has almost all its roots in experimentation on deafferented lower animals. Deafferentation involves procedures to "... to surgically deny afferent input from a movement by sectioning the dorsal roots of the spinal nerves"[32] (Adams 1987:60). The chief argument then - forming the basis for a generalization from animal to human motor behaviour - is that "[d]eafferented animals typically show some competence ... [thus] the agents of movement do not always need peripheral information and so must be central".

The first line of evidence warrants some further arguing here. Lashley, the originator of the motor programming idea, according to Sidnell (1986:9) held as basic evidence for the existence of motor programs the high trilling speed of concert pianists[33], which supposedly does not leave enough time for proprioceptive feedback. Sidnell, however, is of the opinion that "... most musicians would not agree and could show that feedback is a part of this high-speed rhythmic motor behavior". Of interest here is aural feedback in particular; Wolff (1972:177) in fact describes how Schnabel *listened* to the rapid repeats of the lower note of his trills (rather than to both trill notes equally). Supporting Sidnell's notion, MacKenzie (1986:26) cites results from the field of motor behaviour research in speech, which are sufficiently strong to challenge Lashley's belief that sixteen movements per second are too fast for the incorporation of feedback. This research pertains to auditory feedback in particular, which seems promising, as more findings exist with respect to extremely fast feedback involving other than the auditory facilities.

2.8.3 Motor programs and feedback

While Kerr's (1982:37) definition of the motor program (which corresponds with the earlier definition supported by motor theorists) as "... a sequence of movements, which are performed automatically without any apparent thought ... characterized by its lack of ongoing feedback control" apparently excludes the possibility of feedback, the role of feedback - which does in fact take place - in the motor programming context warrants some further discussion. The main idea here is that, while the motor program does not need feedback from the response to successfully execute the movement, error correction can however be applied, if the movement is somehow perturbed from its course by means of feedback transmitted centrally. This notion was apparently supported by Matthay; in this regard, Bridges (1985:34) points out that Matthay

> ... did not believe in a totally automatic technique. At all times there must be feedback in the

[32]Afferent input can be described as sensory information supplied from the peripheral organs to the brain (Kerr 1982:189).

[33]In the order of sixteen notes per second.

> form of semi-conscious attention to the kinesthetic sensations of piano playing in order to adapt to any exigencies in the music concept.

According to Schmidt (1988b:228), the functions of sensory information with regard to motor programs can be organized with respect to the time periods

- prior to the movement
- during the movement
- following the movement

Prior to the movement, feedback information is used mainly as information about the initial position from which the movement is launched, or "... perhaps to tune the spinal apparatus" (Schmidt 1988b:265). Evidence has however been found to suggest that

> ... the system can program a joint position without any information about where the joint was before the movement began. ... But various [other] lines of evidence ... indicate that it does not always work in this way ... (Schmidt 1988b:228)

Information about the initial position of the movement is of particular importance for open skills, where the environment is unpredictable, and thus appears not to be of critical importance for piano playing.

During the movement, feedback seems to have a monitoring function in the sense that feedback from the movement is picked up and subjected to processing, but not used to control the movement unless something goes wrong. Schmidt (1988b:232) cites here one of his rare practical examples of immediate relevance for piano playing:

> It is probable that a long string of actions dealing with finger movements in piano playing are programmed and carried out open-loop. Feedback from the fingers is returned to the central nervous system for analysis, as if the central nervous system were "looking for" errors. If no errors appear, then the feedback is ignored. But if the feedback indicates that an error has occurred, then attention can be directed to that feedback source, and an appropriate correction may be initiated.

Feedback *following the movement* is used mainly to determine how successful the outcome of the movement was. Motor learning is benefited in that the movement can be adjusted on a subsequent trial to attempt elimination of errors made in previous trials.

2.8.4 The generalized motor program

To compensate for the fact that, according to Adams (1987:60), "[n]ot every movement segment is assumed to have its own motor program, because it is believed that memory could not store them all", Schmidt in 1976 proposed the concept of what can be termed the generalized *motor program*, or "[a] motor program whose expression can be varied depending on the choice of certain parameters" (Schmidt 1988b:265). Succinctly stated, the program is considered to be generalized in the sense that it contains "... an abstract code about the *order* of events, the *phasing* (or temporal structure) of events, and the *relative force* with which the events are to be produced". Movements with specific characteristics can be accommodated by a generalized program through the selection of movement parameters "like force, duration and movement amplitude" (Adams 1987:61). Simply by varying the parameters, the performer should be able to account for a large number of movements with a single program.

It is necessary for a proper understanding of the model to differentiate more closely among the invariant aspects, and variable parameters, of the generalized motor program.

Invariant features that are structurally built into the generalized motor program include (Schmidt 1988b:265)

- the order of events
- the temporal structure, or phasing, of events
- the relative force with which events are to be produced

The phasing of events is concerned with the durations relative to each other - which is extremely important for piano playing for reasons that are rather obvious. When the overall durations of two movement sequences are different, but the ratios of durations of underlying activity of muscles in each case are the same, it can be said that these sequences probably share the same generalized motor program. A similar argument can be conducted for the way in which programs are structured, with respect to the forces that are applied.

According to Schmidt (1988b:255,265), the *variable* parameters of the generalized motor program for which the strongest evidence exists are

- the overall-duration parameter
- the overall-force parameter
- the muscle-selection parameter

The *overall-duration parameter* "... defines the overall duration of the program's action" (Schmidt 1988b:266). While the invariant components of the generalized program include basic sequencing and phasing, only the rate of execution of the *complete* pattern can be sped up or slowed down through assigning a different overall duration parameter. The compression of time intervals within these sequences may however not always be uniform, indicating that changing the overall duration parameter has effects "... more complex than had been originally thought, perhaps because of complexities in the muscle properties in fast movements" (Schmidt 1988b:252). A good example of a generalized program which is often required to employ a different overall duration parameter, would be the program functioning to control gait, i.e. the carriage of the human body in moving between destinations (Schmidt 1988b:251): "... the walking pattern (or program) appears to be generalized across different walking speeds, so that we can walk faster or slower by applying an overall speed parameter, keeping the phasing constant". Some reservations do however exist; Handel's (1986) findings, questioning the validity of Schmidt's concept of the generalized motor program, will be discussed in Section 5.3.7.

The function of the *overall-force parameter* in the generalized motor program, according to Schmidt (1988b:266) is to "... [scale] the forces with which the participating muscles will contract in the action". An example from piano playing would be that of a pianist having to proportionally scale up all forces applied to the keys in order to compensate for a piano with a heavier action than one which he is used to. Whether, however, dealing with "difficult" pianos is that simple, is debatable, such a matter being dependent on *inter alia* the sophistication level of the technique of the particular pianist.

Schmidt (1988b:266) describes the *muscle-selection parameter* as "[a] parameter of the generalized motor program related to the selection of the muscles or limbs that will be used in the response". A possible application of the muscle-selection parameter with respect to piano playing, will be pointed out in Section 2.8.5.2.

2.8.5 A motor programming approach to aspects of co-ordination in piano playing

2.8.5.1 The concept of coordination

Perhaps the most often - and most indiscriminately - used term in discussions on piano technique in the literature on piano methodology, is that of *coordination*, which can be defined as the "[b]ehavior of two or more joints in relation to each other to produce skilled activity" (Schmidt 1988b:265). Ortmann (1981:99) describes from a physiological perspective the difference between coordinated and uncoordinated movements as follows:

> A coördinated [sic] movement is a movement which fulfills the requirements of arm-weight, space, and time with a minimum waste of physiological energy. An incoördinated movement is a movement in which this minimum is not reached.

The excessive "waste of physiological energy" associated with an uncoordinated movement may be due to "incorrect weight, distance, or time, as a result of which the aim of the movement is either not fulfilled, or is fulfilled by an expenditure of energy greater than is necessary for particular movement". Fielden (1961:66) emphasizes the importance of correct timing of contraction and relaxation of muscles for coordination:

> Stiffness in playing arises from too much contraction beforehand - nervous tension and fear of weakness at the critical moment: too much relaxation before this movement, on the other hand, leads either to flabbiness or to hard, thumping tone. True suppleness lies in securing the full contraction at the right moment, neither before or after: this constitutes *perfect timing*.

Taylor (1979) uses the term coordination in a broader sense than it is used in the definitions above, by essentially regarding the possession of coordination as synonymous to the possession of good technique; in fact, Taylor (1979:18) regards a person's inherent capabilities with respect to coordination and talent for piano playing as inseparable:

> Talent may ... be expressed as *capacity for co-ordination*. It is this that the prodigy instinctively relies upon to provide his means of performance without training and guides him to success as a mature virtuoso.[34]

The fine coordination found in piano playing is described by him (Taylor 1979:18) as "... a particular interaction of brain, body and keyboard which intrinsically precludes any misdirected effort". Taylor (1979:24) emphasizes that (affective) mind[35] and body can not be separated in the matter of coordination. He supports his position by noting that "[p]sychic tensions can create neck tensions which in their turn have a deleterious influence on the general posture", thus affecting coordination adversely. On the other hand, those *improvements* of a sudden nature that occur from time to time in the motor aspects of a student's performance, can also be explained from this point of view:

> ... [a] release of psychic tension would have expressed itself as a release of physical tensions which would have reacted on the total posture sufficiently to ensure that the student made a better use of himself when he came to play the piano.

Any deficiencies in technique can be attributed to a lack of coordination: "... clumsiness in general, and technical failures in particular, have no other origins than in the making of simultaneous contradictory gestures" (Taylor 1979:39). Therefore, when a person's capabilities for coordination increase, the usual technical problems, for example the playing of scales, arpeggios, double thirds, *et cetera*, "... tend to whither away" (Taylor 1979:40).

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[34]In view of the above it is rather interesting to note that even concert pianists from the foremost rank have technical problems - or problems with coordination in the sense used by Taylor - in some areas; according to John Browning (Noyle 1987:28), Vladimir Horowitz had trouble with unison scales, while Browning himself is " ... not comfortable with fast double thirds".

[35]A detailed examination of the possible effects of affective factors on motor performance, falls outside the scope of the present study.

It is of some interest to note that Taylor (1979:39) regards coordinated movements as being of an essentially simple nature. In support of this viewpoint, Thiberge, as quoted by Taylor, states that "[t]he superiority of the virtuosi stems less from their exceptional facilities than from the extremely simple and natural means which they have discovered of using them".

Inextricably interwoven with Taylor's concept of coordination, is his notion of the use of postural control to increase the capacity for coordination; this matter will be examined in detail in Section 4.2.2.3.

2.8.5.2 Coordination between the hands in piano playing

In the field of piano playing, the term coordination often refers to the way the hands combine in the act of piano playing. In Section 2.4.3.3, which deals with interference among movements following the stages of information-processing, the difficulties of performing simultaneously, i.e. hands together, tasks with different temporal structures, have been pointed out. This phenomenon has been explained in terms of the limitations of the ability of humans to construct and execute motor programs; only one temporal structure can be organized and executed at a time. Therefore it is preferable that the individual parts, corresponding to each of the two hands, should have the same underlying temporal structure.

The present section deals especially with conditions that would probably *enhance* the coordination between limbs, in particular the two hands in piano playing. The question of whether one should practise hands together vs. hands apart is also addressed. Once again, motor programming theory, in particular the concept of the generalized motor program, offers explanations for the various phenomena discussed here.

An important, but relatively rare, condition in piano playing, where interference between the hands is restricted to a minimum, as pointed out by *inter alia* Kochevitsky (1967:12), is when one hand executes a mirrored replica of the movement patterns of the other. This is a condition which can perhaps be illustrated most effectively by writing with the non-dominant hand, a mirror image of the words of the dominant hand (e.g. one's name). An analogous example from piano playing is the execution of the diminished seventh arpeggio on B with the one hand, and the diminished seventh arpeggio on F with the other hand in contrary motion. Schmidt (1988b:258) explains why the former procedure is a relatively easy one:

> ... the motor programs for writing - usually directed to the muscles in the dominant hand - were simply coupled to the "same" muscles of the non-dominant hand at the same time. This is consistent with the idea that the selection of the muscles is a parameter that can be applied to a more fundamental and abstract motor program for signing your name.

Schmidt (1988b:258), however, continues to note that

> [t]his kind of analysis does not ... explain why I cannot simply link the program for writing with the right hand to the muscles with the left hand when it is performed alone. Perhaps, with a great deal of practice, I can ...

Thus, piano-technical tasks, in which the two hands play simultaneously patterns which are mirror images both in the sense of finger movements as well as the topography of the keyboard, should gain from practising hands together rather than hands apart.

Because it possibly could have some relevance to skips at the keyboard with the hands moving in different directions, the conclusions drawn from experiments by Kelso, Southard and Goodman (1979), involving the right hand moving to a large target removed a short distance to the right - with the left hand simultaneously moving to a small target removed a large distance to the left, are also mentioned here briefly. While common sense would predict that the hands should reach their respective targets at markedly different times, it was found that the two hands arrived almost simultaneously -

> ... the two hands appeared to be locked "together" , in that the time of maximum height of the hand, the time for peak acceleration, the shapes of the trajectories, and so forth, were remarkably similar for the two hands. (Schmidt 1988b:259)

As Kelso et al. (1979:1029) phrase it,

> [t]he hand moving to an "easy" [i.e. nearby] target moves more slowly to accommodate its "difficult" [i.e. far off] counterpart, yet both hands reach peak velocity and acceleration synchronously.

According to Schmidt (1988b:260), the explanation for this phenomenon can be interpreted as follows: both hands are controlled by the same general motor program, with phasing characteristics - one of the invariants of the generalized program - being the same in the movements of both hands. But

> [o]ther features ... such as the distance the limbs traveled, appeared to be easily changed between the two hands, and we interpreted this to mean that distance was determined by parameters to the two limbs (an overall force parameter) that were selected differently for the right and left hands.

Along similar lines it is worthwhile to mention here Schmidt's (1988b:416) view on practising hands together vs. hands apart in piano playing[36]: according to him, two-handed piano playing appears to be controlled by a single motor program; therefore

> [p]racticing the movements of one hand in isolation probably results in the development of a different program than practicing that "same" movement in the context of a total two-handed skill ... However, there appear to be contradictions; left-hand piano ... practice seems to transfer to two-hand performances.

These "contradictions" would probably include cases like the Chopin *Etudes*, Op. 10 No. 1 and 2, where the right hand is involved in the execution of highly intricate movement patterns, while the left

[36]Some additional comments in this regard will be made in Section 5.4.2.

hand is merely playing a simple accompaniment. The coordination between the hands is a rather simple matter in cases like these.

In view of the above, it is rather interesting to note Gieseking and Leimer's (1972:52) viewpoint that it is *not* advisable to allow both hands, in the initial stages at least, to play together when executing scales, but for a different reason, which involves the quality of aural feedback: if the hands do not play separately, "... the left hand is drowned by the right hand, or *vice versa*; for it becomes almost impossible to find out the grade of strength of the different tones with the two hands playing together".

This section is concluded with a statement of Schmidt's (1988b:260) *caveat* that, despite some promising initial investigative attempts, very little remains known about the coordination among limbs that form the basis for complex skilled behaviour:

> [w]hat other patterns of "natural" coordination might exist, as well as which of them are most easily learned, are issues which need considerably more study before we can effectively understand complex skills.

2.8.6 On the extent to which movement is specified by motor programs

Various possibilities exist for the characteristics of the actual instructions comprising motor programs. An older notion that point-to-point computational models, "... in which each point in the trajectory of a movement is represented and achieved by the motor system in the response", is currently regarded as far too complex and improbable to have been achieved by the human control system (Schmidt 1988b:265).

Instead, attention has recently been directed at a dynamical systems approach to motor control, in which the influence on the movement pattern of physical and mechanical properties of muscles and bones are taken into account[37]. Such influences would imply that those aspects of motor control, determined by the mechanical properties of moving masses and the spring-like and oscillatory properties of muscles, do not have to be accounted for centrally by the motor program; thus Schmidt's (1988b:265) observation that

> [c]ertainly, not all of the limb's movement is represented "in" the motor program.

[37]Apparently, this shift in focus is not inherent to the traditional motor systems approach to motor control, as can be deduced from the viewpoint of Bernstein stated in Section 2.9.

The dynamical systems approach, which is regarded by certain action theorists as an important supporting factor for their viewpoints, will be treated more fully in Section 4.2.7.

2.8.7 A motor programming approach to rhythm and timing

2.8.7.1 Demands posed by rhythmical organization in music on the motor system

The present discussion of the motor programming concept is concluded here with a discussion on how rhythm and timing is maintained in a skilled piano performance. *Rhythm* is defined by Apel (1970:729) as

> [i]n its primary sense, the whole feeling of movement in music, with a strong implication of both regularity and differentiation. Thus, breathing (inhalation vs. exhalation), pulse (systole vs. diastole), and tides (ebb vs. flow) are all examples of rhythm.

Timing in music depends on three different rhythmical entities, namely the *beat*, the *meter*, and *temporal pattern* (Shaffer 1982:109). The term *beat* signifies "[t]he temporal unit of a composition, as indicated by the up-and-down movements, real or imagined, of a conductor's hand (upbeat, downbeat)" (Apel 1970:87). *Meter* is "[t]he pattern of fixed temporal units [i.e., beats] ... by which the timespan of a piece of music or a section thereof is measured" (Apel 1970:523), while *temporal patterns* are constructed through "... joining and subdividing beat intervals to create a series of note and pause durations" (Shaffer 1982:109).

Shaffer (1982) proposed a general theoretical framework to deal with rhythm in its different manifestations associated with skilled activities such as playing music, certain games in sport, and human speech. In each of these types of activities rhythm will differ with respect to stress, periodicity, expression, quality of movement, and temporal pattern.

In order to form a more complete understanding of what would be required of the motor system regarding rhythmical organization in music, it is necessary to consider in particular the rhythmical senses of stress, expressiveness and quality of movement.

In musical performance, rhythmical *stress* has the effect that the listener "... can interpret the meter and clap more vigorously on the strong beats" (Shaffer 1982:110). Stress, however, is not necessarily confined to the meter, and rhythmical variety is typically obtained through redirecting stress from a strong to a weak beat. *Expressiveness* by means of timing is established through judicious tempo variation which involves slight lagging or leading the beat. Rubato, which has been described earlier (see Section 2.4.3.3), falls in this category. The importance of expressive use of timing is emphasized by the statement of Shaffer (1982:110) that

> [a] musician who plays squarely on an inflexible beat definitely has not "got rhythm".

Shaffer (1982:110) describes *quality of movement* in an accomplished performance as follows: the performer "... gives the appearance of being unhurried, fluent, and avoiding abrupt accelerations". It follows intuitively that, to achieve fluency, movements have to be prepared in advance of note production, and to achieve a fluent phrase or period, programming has to take place even earlier. It therefore becomes clear that a theory of rhythm should account for, not only the timing of discrete events, but the underlying continuity of motion as well.

2.8.7.2 The concept of an internal timekeeper or clock

For all skills displaying the property of being nearly periodic at some level of the performance, Shaffer (1982:115) proposes that some internal timekeeper, or clock, is present with the ability to construct a required time interval. This assumption appears to be all the more valid for music, which is governed by a beat. The analogy, although rather obvious, should be pointed out here: at the heart of any digital computer system, is an internal clock which provides a regular pulse by which all activity in the system is structured and regulated.

The internal timekeeper of the motor system presumably uses two basic methods (Shaffer 1982:117) for timing a rhythmic group of two beat intervals, from which a variety of more complicated timing structures can be compiled, namely the *concatenational* and *hierarchical* methods. The former simply involves generating the intervals in serial connection, while in the hierarchical method the group interval and the first beat interval are generated; from these the second interval is then determined. In a study involving a statistical analysis of the relationships between time intervals in a Bach *Fugue* from *Das Wohltemperirte Klavier* (Shaffer 1981), Shaffer (1982:118) found that time intervals half a beat in length were apparently generated mostly in concatenation. What made these time intervals of particular importance, was the fact that their length was the same as the note duration found most commonly throughout the piece. On the other hand, the durations associated with shorter notes within half-beat intervals were probably constructed in a hierarchical fashion, "... supporting the idea that the motor system constructed a compound movement trajectory to produce short notes".

On the expressive use of timing, which involved deviations from the beat in both performances in a similar manner, Shaffer (1982:118) notes that

> [h]ere we must suppose that expressive information in a motor program was used to modulate the clock rate. In the nature of our assumption that the motor system uses clock pulses as temporal reference points, it is necessary that both levels of timekeeper, clock and motor system, should receive the expressive information so that they can negotiate chances in tempo

without becoming radically out of phase.

In Section 2.4.3.3 the difficulty has been pointed out of executing, at the same time, different metric structures with each hand due to a lack of parallel processing capacity in the later stages of information-processing. Shaffer's study (1981:344 ff.) of a pianist performing the first etude from Chopin's *Trois Novelles Etudes*, in which the performer is required to execute polyrhythms of three against four, provides some new insight into this matter. The fact that the pianist was able to manage performing the etude with some expressive timing effects like rubato, and "... one hand moving off and back onto the beat", yet preserving the proper mathematical division corresponding to three and four notes in the beat for the hands respectively, signifies according to Shaffer (1982:118)

> ... the use of a hierarchy of timekeepes: a flexible clock to time the beats and timekeepers in the motor subsystems, one for each hand, to construct the appropriate subdivisions of the beat and allow one hand to move off the beat.

Shaffer (1982:118-119) thus concludes that evidence exists for a clock in piano performance of which the rate can be varied according to the need for expressiveness - "[a] motor system can produce compound movement trajectories that subdivide clock intervals and can undershoot or overshoot clock references in a controlled way".

An interesting side consequence of the work done by Shaffer (1981,1982), is the pointing out of the fact that many research problems concerning skilled motor performance, are not addressed through the traditional methods of introducing subjects to arbitrary laboratory tasks; simply because certain aspects of skilled performance - for instance the expressive use of timing in piano playing - have no counterparts in unskilled activities.

2.9 Limitations of the motor systems approach as seen from the action systems perspective

It can safely be stated that action theorists have at least two major objections against the motor systems approach to motor control.

According to Schmidt (1988a:6), the main point of difference between motor theorists and action theorists has bearing on the concept of the motor program: "[f]or the action proponents ... the notion that some movement programme stored in the CNS is responsible for the controlled actions has been particularly distasteful ...".[38] The reason for this "distaste" is the fact that explaining motor behaviour as ruled by the motor program, simply causes other questions of similar magnitude and significance to arise,

> ... resulting in a logically infinite regress. ... if details of ... the timing of an action are controlled by a programme, then how is the programme structured, 'who' structured it, and what are the rules for its formation? (Schmidt 1988a:6-7)

Motor theorists apparently do not have much to offer in response to questions on where motor programs come from; Schmidt (1988b:483), while acknowledging the importance of the problem, simply states that "... the level of knowledge at this time does not allow much to be said about this process [of origination of motor programs]".

Schmidt (1988a:7) singles out as a further argument of particular significance against the motor program, Bernstein's (1984) notion that

> ... it is ... impossible for the CNS to be able to 'compute' the exact commands needed for a particular action ...[39]

This implies that a central motor command cannot determine action unequivocally (Bernstein 1984:82), the reason being that the command can be modified before actual execution due to either sensory information becoming available, or the state of the limb(s) caused by the command just prior to the command being executed:

> ... sensory information from the responding limb (and elsewhere) can exert its influence as the movement is unfolding, thus modifying any central command structure before it is received at the muscle level. ... [Also], various sources of muscle non-linearities make the forces produced by a given central command different depending on various initial conditions in the limb and muscle.

Action theorist's alternative for the motor program, namely accounting for order in movement patterns through the dynamical properties of the moving limbs, will be examined in Section 4.2.7.

A second major objection, in this case aimed against the traditional methods for studying motor behaviour, is stated by Sloboda (1988:vii); it involves the rather easily-observed phenomenon that problems of measurement in motor behaviour science led to the concentration within the psychological community on tasks that are relatively simple -

> [i]t is always easier to collect one's data in the form of responses from a limited and pre-ordained set (for example yes-no decision, same-different decisions) than it is from relatively unconstrained and multi-dimensional behaviour.

In addition, the difficulty exists of devising suitable controls over experiments involving generative behaviour; without such controls it becomes increasingly difficult to extract generalities, which in the

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[38]The acronym CNS stands for central nervous system.

[39]This fact has of late been recognized by some motor systems theorists as well, as was indicated in Section 2.8.6.

end is what a scientific investigation is all about (Sloboda 1988:viii).

A similar position is held by Mulder and Hulstijn (1988:253), who regard as a major deficiency of the motor systems approach, the artificiality of its theories, which are derived from simplistic experiments in an impoverished controlled environment: " [t]oo often movements are unduly trained and studied independent of the actions of which they are elements" (Mulder & Hulstijn 1988:254). In the context of piano playing, similar ideas are voiced by certain pedagogues; Thiberge, as quoted by Taylor (1979:38), held the rather disconcerting view that it is of little use to study in isolation (for instance) the contrary muscular exertions of which the body is capable:

> As all the parts of the body are so intimately bound up with each other, the entire body of the pianist is capable of giving rise to exertions which are destructive to the suppleness of the fingers, and for that matter, the suppleness of the limbs in general.

Even Schmidt (1988a:11), who conceived the generalized motor program, notes that motor processes initially went through an evolution in order to help the animal adapt to his environment; therefore

> ... principles learned from experiments in artificial and constant environments may be at worst fundamentally different from those involved in real animal-environment situations, or, at best, may simply be irrelevant to them.

Finally, Reed's (1988:79) denouncement, in rather harsh terms, of the cybernetics concept and its predecessor trends in psychology deserves some attention:

> This so-called 'science of human movement' *assumed* that all acts could be standardized and timed into 'optimal responses'. ... These scientists emphasized the need to act quickly, on a signal, and to quickly modify responses through sensory correction. ... The human brain began to be treated as a little machine inside the bigger machine of the body, the body being the 'interface' to other machines and the environment for the brain. To put it bluntly, the modern sciences of human movement have tended to treat our actions as though they were the constrained movements of a gunner or a welder on the assembly line.

The different, supposedly "better" approaches to motor control advocated by action system theorists will be treated in Chapter 4[40].

2.10 Summary and conclusions

Piano playing, due to its complex nature, apparently displays the characteristics of both serial and continuous motor tasks. Any piece which in refinement approaches concertizing standards, apparently assumes predominantly continuous characteristics. This is because attempts to create a musical *Gestalt*, would probably de-emphasize any pronounced demarcations into the constituent element

[40]In Section 4.2.3 some additional criticism of the motor approach will be presented on account of its inability to explain postural precedence effects.

sections of the piece. Whether piano playing is regarded as a closed or semi-closed skill will depend on the nature of the learner's involvement with music. Apparently, the matter of explicitly accounting for piano playing as a semi-closed skill in a strategy for practice, is largely ignored in the piano methodology literature.

Methods have been described for quantifying scientifically both movement characteristics and movement outcome. Methods currently employed in the psychological community for measuring movement characteristics could be difficult and cumbersome to employ in studying motor responses in piano playing, simply because of the large range of small muscles and the great variety of refined movements involved. Describing movement outcome - for instance through using the experimental techniques of Shaffer - appears to be a viable proposition for studying certain aspects of the performance. Also, it should be possible to investigate in a similar manner the presumed variables of the generalized motor program; an increased overall-force parameter, for example, would manifest itself in higher hammer shaft speeds, which can be detected electronically. It is redoubtable whether measuring movement speed in piano playing through reaction time tests would be of much significance, as there are simply too many refined complex movements, most of which are interrelated, which constitute the act of piano playing. The implicit understanding associated with measures of speed, that accuracy is of less importance than rapid actions, does not appear particularly attractive to piano playing either.

It was pointed out that motor system theorists regard man as a so-called "black box", which processes input signals from the environment in order to output appropriate motor responses, and that from overt human behaviour observed inside the laboratory and in everyday life, it can be inferred that information-processing takes place in three stages. The significance of studying these stages in piano playing will essentially depend on the nature of the movement task. In the initial stages of getting acquainted with a passage, it is reasonable to assume that a motor response could be the equivalent of playing a single note. Then, the three stages of processing could, among various possibilities, typically proceed as follows: the aural stimulus is the note played just before, and it is recognized in the context of the passage; a motor response is selected from any number of combinations of finger movements relating to different keys on the keyboard, and finally the muscles of the appropriate finger(s) are readied to strike the right key or combination of keys; in the case of for instance a five-finger run, a short motor program would be prepared. In a polished performance of a piece consisting of many hundreds of notes, the playing of a single note can hardly be conferred the status of a fulfledged motor response; in this case, what comes next is determined mainly by motor programs acquired through extensive practice.

Much uncertainty is prevalent on the subject of motor memory. The conceptual distinction between short-term memory and long-term memory is at the present time regarded to be of little significance. It is not clear if and how knowledge of the concept of the short-term sensory store, could aid control and learning of the problems involved in piano playing.

It was found that the lack of continuity in the response-programming stage suggested by the phenomenon of psychological refractoriness - movements can only be produced in discrete bursts spaced at intervals of at least 200 msec. - should not influence the "flow" of action in piano playing, especially in view of the fact that each of the discrete bursts of movement may be controlled by a motor program, and thus movement may be maintained for sufficiently long (i.e. 200 msec. at the least) until the next set of movements arrives, ensuring continuity.

In the execution of motor responses following the stages of information-processing, the question of automaticity comes strongly to the fore. No kind of information-processing seems to be entirely free of interference. It was pointed out that a task should only be thought of as automatic with respect to some other, secondary task. Two tasks carried out without apparent interference, however, does not necessarily imply automaticity, because it is possible that the two tasks simply use different processing facilities. More investigation is needed to determine whether this notion is of particular significance for piano playing. The massive interference that occurs when two tasks with different underlying temporal structures have to be executed, for example the application of rubato, can be explained by using the argument that movements are organized by the motor system under a strong temporal structure. It was furthermore pointed out that no conclusive evidence exists for the progression in motor activities from controlled information-processing to automatic processing via practice, which intuitively seemed a most acceptable proposition.

It appears as if knowledge of spatial and temporal anticipation can serve to clarify aspects of motor control in piano playing, especially if it is assumed that timing is organized by some sort of internal clock in the motor system. Spatial anticipation in (slow) piano playing could occur as follows: the playing of a particular note would serve as a "warning signal" for the next note, so that the performer will be ready when the actual stimulus, for example the next beat or its relevant subdivision as supplied by the "internal clock" of the motor system, arrives. Due to the fact that piano playing is a rhythmical activity, the pianist can easily anticipate in a temporal sense when the next stimulus will arrive, resulting in an essentially simultaneous response with the stimulus. Anticipation can, however, be detrimental in that anticipating the musculature conditions required for a certain response, could inhibit execution of the current movement pattern for which a different configuration of the playing apparatus is needed.

The often-observed fact that too much arousal can be detrimental to piano playing, especially in the case of public performance, can apparently be explained from an information-processing viewpoint: because of perceptual narrowing, the performer's ability to distinguish between relevant and irrelevant stimuli is adversely affected, which consequently takes its toll on the performance. As with so many areas in motor control, the question regarding optimum arousal levels is not cleared up yet; it is however worthwhile to note that constant exhortations to "try harder" may produce just the opposite to the intended effect.

Three models from control engineering were proposed to account for human motor control, the closed-loop and open-loop models being the most important. An extremely attractive feature of these models is their underlying simplicity. As most of the motor systems theorizing on motor learning and motor programming are based on these models, the question could be raised of whether these models are perhaps too predictable in their simplicity and regularity to account for the infinitely rich variety of movements humans are capable of, not the least manifestation of which is playing the piano.

Although motor programs are seen as open-loop methods of control, some use is made of feedback to correct errors, if any, during execution of the program. Therefore, the notion that a section involving rapid passage work is controlled "automatically" by a motor program, should not let the performer refrain from monitoring his playing through constant listening, because the concept allows for adjusting the program to compensate for errors in the execution of the program as well as unforseen environmental effects, such as a piano with an uneven action.

The generalized motor program concept was introduced to improve the original motor programming idea; it also raises some questions, however. To illustrate some of these questions, consider a virtuoso Chopin *Etude* as controlled by such a program. Changing the overall-duration parameter would imply speeding up or slowing down the tempo as desired, while changing the overall-force parameter, would suggest that all dynamic levels can be scaled up or down, maintaining their relative proportions. However, it does not take a particularly astute perception of the problems of piano playing to realize that only the most accomplished of pianists would be able to meet these demands. Perhaps this implies that the best pianists are the only persons who know how to properly structure generalized motor programs in piano playing. Further research is necessary to clarify this concept with respect to piano playing; some more findings in this regard will be discussed in Chapter 5.

The term coordination can be shown to incorporate under its banner a fairly wide variety of meanings, which apply to *inter alia* movements *per se*, and talent for piano playing. Apparently however, explanations, based on motor systems premises, of coordination problems in piano playing, pertain mainly to the coordination between limbs, i.e. the hands, in piano playing. In particular, a generalized motor programming explanation was offered for the relative ease with which the hands execute parts that are mirror images of each other. Of quite some importance was the pointing out of the notion that practising one hand alone, probably results in a different motor program than practising the movement patterns of the same hand in the context of the two-handed skill. When the other hand merely adds a non-exacting accompaniment, it is probably in order to practice the "difficult" hand alone, as coordination between the hands is relatively easily obtained. Once again, more research is necessary to fully understand the complexities of coordination between limbs, in particular the hands in piano playing.

Not all the intricate - sometimes microscopic - details of movements are identified in and controlled by the motor program; some of these movement characteristics are accounted for by the mechanical properties of the relevant muscles and limbs. According to certain action theorists, *all* movement characteristics can be explained in this way; this matter will be taken up for further discussion in Chapter 4.

Shaffer's notion was discussed that rhythm and timing in piano playing can be accounted for by the digital computer concept of an internal clock. In fact, all nearly-periodic skills can be thought of as structured in this way. For the execution of polyrhythms divided between the hands with expressive timing effects superimposed, two flexible clocks are used, one for each hand. Shaffer's investigations brought another point to the fore, namely that highly-skilled motor tasks, such as piano playing, cannot be addressed by laboratory experiments involving simple motor tasks and unskilled test subjects, because certain aspects of skilled performances have no counterparts in unskilled tasks. Thus, due to the large investment in time required for unskilled subjects to become skilled in some task, many aspects of skilled motor behaviour remain uninvestigated.

Two major objections of action systems theorists against the motor approach were singled out. Firstly, action theorists categorically deny the existence of central control, i.e. motor programs. If this premise should prove to be true, most of the above notions and conclusions would apparently be rendered irrelevant. The second objection involved the irrelevancy for highly-skilled motor tasks (like piano playing) of experiments involving simple, unskilled motor tasks performed in an impoverished controlled environment. This objection is of considerable significance, especially when it is realized that all theories of motor control and learning have in the first instance to be based on some sort of experimental premise.