A Model for Hierarchically Ordered Schemata in the Control of Skilled Motor Action

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1 Introduction

There is an apparent tension between modern theories of motor behavior and Gestalt theoretic approaches to human movement behavior. Especially the notion of motor regulation - a core concept of most modern approaches to complex motor behavior - irritates Gestalt theorists because of its tacit assumption of a homunculus-like executive (MÜLLER 1984). A closer inspection of these approaches, however, reveals that the central problem with them is their implicit Cartesian division of human behavior into a mechanical part, the motor apparatus, and an executive mind. METZGER (1973), for instance, has vehemently criticized such a tendency to invoke objectivity by using terms like mechanism in the context of action and to sever the actor from the actor's movements. Instead he proposes a structural framework for the connection between events and motor behavior ('Motorik' in the meaning of term as LEWIN (1926) has used it) in contraposition to holistic approaches as KRÜGERS (1915) where everything is connected to everything and becomes structured in time due to processes of learning and maturation. METZGER (1973 p. 320), instead, postulates that "wholes of lesser content, in the limiting case: Elements, fuse into more comprehensive wholes due to developmental and learning processes, and old structures become different new ones by means of dissolving and reassembling, that is, they are able to restructure themselves..."

This framework (see also the model developed in ZIMMER 1986) attempts to account for the phenomena of voluntary motor behavior without referring to the dualistic approach of an executive mind and a mechanistic motor apparatus. By stressing the importance of self-activity in motor behavior, METZGER makes way for a Gestalt-theoretic approach to motor behavior that transcends the quite narrow view of KOFFKA (1935), according to whom motor behavior (he, too, refers to LEWINS term 'Motorik') is an activity which merely reduces stress in the organism and results in changes of the perceptual field which have to be taken care of by invariants (passism, especially pp. 342-344). It should be noted here that KOFFKA (1935, p. 342-367) develops a theory of the "control of the executive" that is - at least - implicitly Cartesian. However, this kind of pragmatic dualism is resolved by METZGERS framework.

The goal of this article is to show that the model of interactive schema hierarchies (ZIMMER 1986) specifies METZGERS (1973) framework and allows for an empirical validation. Experiments of ZIMMER (1983) and KÖRNDLE (1983) are reported which support this approach.

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2 The Acquisition of Motor Skills - Phenomena and Theoretical approaches

Many situations in the occupational or recreational life of adult people force them to acquire new skills which depend to a higher or lesser degree on motor actions (WEIMER 1977). These motor actions are either completely new (e.g. achieving a stable gliding position in sky-diving) or they differ from motor actions already available in the behavioral repertory in one or the other respect (e.g. learning to do the square dance which resembles forward and backward walking except for the rhythm). From an external point of view, what happens to the learner in such a situation is the following: The learner perceives a motor action performed by somebody else or (s)he listens, reads, or inspects a verbal, symbolical, or pictorial description of the motor action. What the learner perceives or understands is used by him or her for the initiation and control of the motor action (see ROSENBAUM 1980). The similarity between the performed motor action and the task as demonstrated or described serves as the criterion for the performance of the learner. Usually the motor action is repeated until the new or the modified old skill is acquired, that is, a prescribed performance level is accomplished or the learner him- or herself has the impression that "it simply feels right." This is reminiscent of TOTE-hierarchies (MILLER, GALANTER, and PRIBRAM 1960). However, in that framework it remains unclear how perceiving somebody else's performance or description of a motor action can induce changes in the perceiver enabling him or her to perform the same task. Even if the target motor action can not be performed immediately, it must be assumed that what has been perceived serves a control function in the on-going learning process.

Psychological theories of motor skill acquisition attempt to explain how externally defined motor actions are acquired and become thereby part of someone's behavioral repertory. These theories can broadly be classified into the following categories:

(i) the behavioristic approach (as exemplified by GREENWALD, ALBERT 1968; or SKINNER 1968, where he analyzes how the 'high jump' is learned). The approach is entirely restricted to situational variables and subsequent reactions;

(ii) the systems-theoretic approach (e.g. BERNSTEIN 1967; ADAMS 1971) which is concerned with the question how movement behavior is controlled through comparisons between observable results and internal or external criteria;

(iii) the internal-representations approach (BARTLETT 1932; HACKER 1977), according to which perceptual and regulatory processes are controlled by mental models (CRAIK 1943, JOHNSON-LAIRD 1983); a special variant of mental models for movement behavior are 'motor programs' (see PEW 1966; SCHMIDT 1980.

(iv) the schema-theoretic approach (HEAD 1920; SCHMIDT 1980; ARBIB 1980; ZIMMER 1986 a) which is characterized by the assumption that generalized mental processes (schemata) coordinate on the one hand external information with the internal knowledge and on the other hand intensions with overt actions.

An evaluation of these approaches can be oriented at STELMACH & DIGGLES' (1982) suggestion that theories of motor behavior should be able to explain the following phenomena:

(i) *motor equivalence*

Apparently the same or equivalent movements can be produced by combinations of different groups of muscles. A direct correspondence between neuronal activity and effected movements does not exist (HEBB 1949; LASHLEY 1938)

(ii) *motor variability*

The analysis of apparently identical movements reveals variations in the electromyographic or kinematographic records in spite of constant starting conditions. This is true for repetetive and nonrepetetive movements (BARTLETT 1932; GLENCROSS 1980; SCHMIDT 1975; GENTNER, GRUDIN, CONWAY 1980)

(iii) *The complexity of the motor system*

The number of degrees of freedom in the human anatomy corresponds to the complexity of the motor system. BERNSTEIN (1967) counted 127 degrees of freedom but the more recent analysis of TOMOVIC & BELLMANN (1970) resulted in the number of 792. "BERNSTEINS problem" is the question how to control so many degrees of freedom, which result in at least 2^{127} or 1.7 x 10^{38} possible combinations. It is obvious that effective motor control is only possible if this number is drastically reduced. Therefore a realistic theory of motor control has to specify mechanism for a reduction in complexity.

The behavioristic approach circumvents the evaluations by means of these criteria because it confines itself to a functionalistic view and thereby avoids the question how movements come into existence ('operants' are assumed to occur spontaneously and have only to be shaped by reinforcement). Furthermore mental states and events (the so-called problem of representation and the autonomous processes in memory) are regarded as unnecessary mentalistic assumptions in 'radical behaviorism'. BERNSTEIN's (1967) original approach does meet these criteria only partially. His concept of a 'sensory-motor cycle' control that reduces the number of degrees of freedoms by making use of lower-level autonomy ('synergies') and higher-level 'commands', results in the postulation of a central program-like processing without specifying what is to be understood as information. This leads to severe practical problems when there is motor behavior that improves without external feedback (e.g. knowledge of results). ADAMS (1971) attempts to account for motor plasticity and variability by the assumption that motor behavior is controlled by a motor *and* a perceptual trace. This dual structure of control, however, does not specify how the subsystems are coordinated and furthermore it fails to account for more complex motor behavior than handlifting or pointing. The most ambitious attempt to solve BERNSTEINS problem has been developed by TURVEY, KELSO, and their collaborators (see e.g. TURVEY, FITCH, TULLER 1982, KELSO & KAY 1986). It relies on the phenomenon of oscillatory self-organization in pendulums with external constraints. They have shown that anatomically complex motor behavior as, for instance, walking can be modelled by means of a few positively or negatively damped oscillators. Therefore, the control structure has to take care of only a few oscillators instead of the 32 degrees of freedom of the legs.

This result elucidates the question of what constitutes 'elements' in motor behavior as assumed by METZGER (1973). The complexity of motor behavior is defined by the number of independently controllable processes and not by the number of physically determined degrees of freedom of the anatomical movement apparatus. The problem with TURVEY & KELSOs approach is that its scope is too restricted: Modelling the acquisition of a motor skill or the qualitative characteristics of skilled vs. unskilled behavior is not possible in this framework. SCHMIDT (1975) resolves some of the problems in the BERNSTEIN and the ADAMS approaches by introducing seperate schemata for recognition and recall. His approach fails for the criterion of complexity of the motor systems because he does not take into account that the very characteristics of a motor act change if it is integrated into an action of higher complexity. For instance, what characterizes 'lifting the arm' as part of the service in tennis is different from what characterizes the same movement when produced in context of greeting. This systematic influence of contextual conditions on the execution of biomechanically equivalent motor patterns shows that motor actions, but not biomechanically defined motor patterns exhibit PYLYSHYN's criterion of 'cognitive penetrability' (1979).

The internal-representations approach in perception has been attacked by GIBSON (1979) who pointed out that many effects usually ascribed to processes on or in such internal representations can be explained more parsimoniously by the theory of affordances (GIBSON 1979). According to this theory, perception is characterized by a direct pick-up of information 'afforded' by the environment. The results of RUNESON (1977) indicate how 'smart' the mechanisms can be which underlie the process of picking up available information. A coordinating organization of several such 'smart' mechanisms for information intake and the output of actions seems to be necessary for complex kinds of behavior like skilled actions that are experienced as unitary. For problems of this kind NEISSER (1976) has suggested to assume schemata in perception and cognition as providing the organism with the internal organization necessary for the adaptive utilization of environmental information and the ability to integrate separate actions into holistic or Gestalt-like skills.

3 Schema Hierarchies as a Framework for Motor Learning

The application of the KANTian notion of schemata to the acquisition of motor skills dates back to HEAD (1920) and BARTLETT (1932). In more recent times SCHMIDT (1975) and ROSENBAUM (1977) have utilized this concept in their approaches to motor learning. However, these conceptualizations resemble specific fixed molding forms or static filters and cannot be assumed to fulfill the general organizational function postulated by NEISSER (1976).

ARBIB (1980) has suggested action/perception cycles for the acquisition of motor skills and postulates schemata on the level of neural structures. This approach is in line with the assumption of general organizational functions, but it seems difficult to model cognitive penetrability in it. Therefore a more abstract definition of 'schema' is chosen for which ARBIB's (1980) notion is a special case.

CASSIRER (1944) has suggested an approach to perception based on KANT's concept of schema and group-theoretic models of geometry as proposed by KLEIN and POINCARÉ. This approach provides a framework for the integration of the systems-theoretic and the schema-theoretic view points in the analysis of motor skill acquisition.

The concept of the schema can be defined according to CASSIRER (1944) as consisting of:

(i) *a set of basal units* ('primitives' or elements in METZGERS (1976) terminology) that are not further analyzable in the given context (e.g. reflexes and oscillators underlying simple movements (see GALLISTEL 1980); some theoretical approach reduce the variability of primitives even further. KELSO & KAY (1987), for instance, postulate merely systems of positively or negatively damped oscillators that exhibit self organization in the terminology of HAKEN (see HAKEN & WUNDERLIN 1986)).

(ii) *a set of organizing rules* (e.g. 'Gestalt laws in perception and memory, 'smart mechanism' (RUNESON 1977), or servomechanisms in movement behavior (GALLISTEL 1980)).

(iii) *a set of admissible transformations* that generate invariants of the objects in question (in this case: movements, patterns of movements and motor activities). For instance, the motor activity of writing the letter 'x' can be *invariantly* realized by different movement patterns of hand and arm (see LEWIN (1926) for a first analysis of this phenomenon in writing).

One important consequence of this definition is that the schema of a certain motor skill cannot be reduced to its primitive components and their relations (e.g. aiming movements and the temporal order of them or the tapping of fingers and the frequency of it, see SUMMERS, SARGENT, HAWKINS 1984), that is, (i) and (ii), but that the set of admissible transformations of this skill has to be taken into account too (e.g. the overall rhythms which remains the same even if the general speed is increased or reduced). This view of motor actions is at least partially supported by evidence from physiology (see ARBIB 1980). Of special interest are the behavioral effects of the ablation of the motor cortex (PRIBRAM 1971), namely, that complex motor skills cease to exist without an impairment of particular muscle functions. PRIBRAM (1971, p. 14) concludes "...behavioral acts, not muscles or movements, were encoded in the motor cortex."

4 Paradigmatic Experiments for Motor Schemata

In an experiment on how to learn cutting the spin in table tennis it has been investigated the influence of different instructional methods on the generation of different motor schemata for one and the same task which is defined unambiguously from the point of view of biomechanics (ZIMMER 1983). The two instructional methods were (group I) 'learning the underlying physical principle' including its consequences for the trajectories of a spinning ball, and (group II) 'learning by observing the correct motor pattern'.

In a first analysis it could be shown that group I changed from the state of non-competence (N) to the state of competence (K) without going through intermediate states. In contrast to this, subjects in group II exhibited the pervasive tendency to repeat rigidly the last reinforced movement pattern without taking into account the changed situational variables (e.g. the speed of the ball etc.). However in the end both

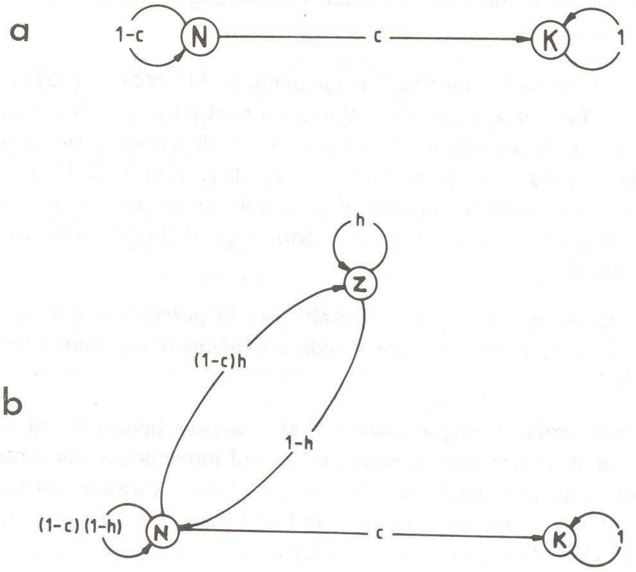


Figure 1: State-transition diagrams for (a) group I and (b) group II.
N indicates the initial state, K the final state, and Z the repetetive state.
c, h, (1-c), 1, (1-h), (1-c)h, and (1-c) (1-h) are the transition probabilities.

groups learned the topspin, that is, they arrived at the same correct motor pattern. The state-transition diagrams in Figure 1 describe the differences in complexity of the learning process for the two experimental groups.

In the second part of the experiment the subjects had to learn the undercut. This task was chosen because from the point of view of mechanics the underlying invariant (the tangential impulse on the ball) remains the same for top-spin and for undercut. However, the required muscular activities are completely different. Therefore it was expected that the schema of the task oriented at the physical model would facilitate transfer. In contrast to this, a purely motor or visu-kinestetic schema (as it can be assumed for group II) should not be conducive to an immediate mastering of the new task.

In group I 6 out of 10 subjects were immediately able to perform the undercut (i.e. the transfer task) whereas only 1 subject out of 10 in group II was able to do it. This result can be interpreted in the following way: The 'successful' subjects in group I had learned the schema 'spin' which is characterized by all transformations on actions which cause a rotation of the ball and thereby influence its trajectory. The subjects in group II had only acquired the schema 'top-spin' and had to learn the 'undercut' as a new schema. However, the times necessary for the acquisition of the new schema reveal that the subjects in group II have been able to utilize the preceding practice partially: Their learning times are significantly shorter than the learning times for those subjects in group I who failed to identify the new task as a transformation of the schema 'spin'. This result indicates that there is one important negative consequence of the reduction

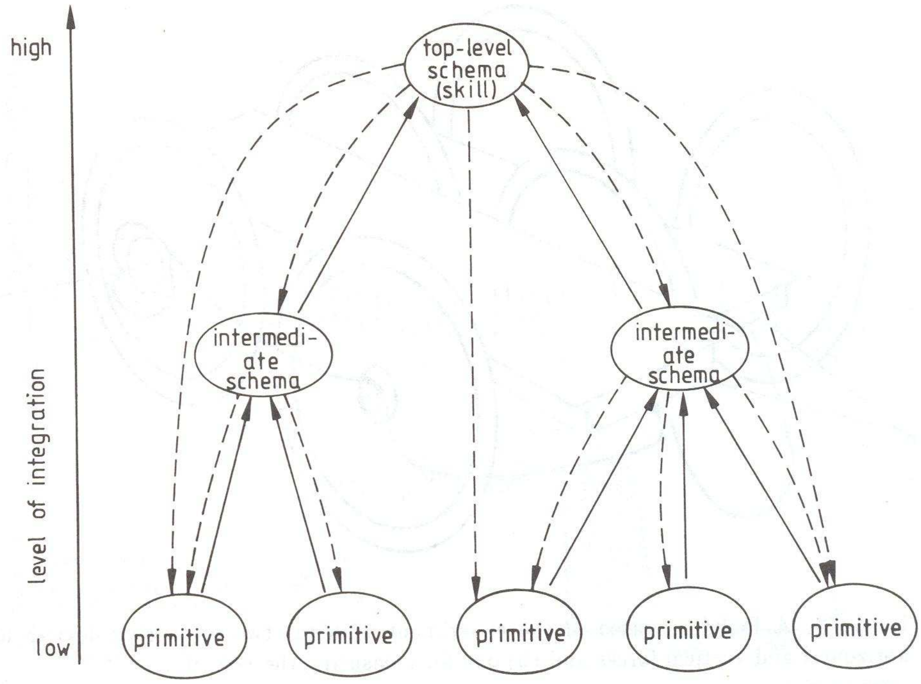


Figure 2: The model of schema integration (→) and downward constraints (⇢).

of complexity by integrating motor schemata into an interdependent hierarchy, namely, that this integrated structure does not allow for an utilization of partial knowledge. An example for such an interdependent hierarchy is shown in Figure 2.

In this graph schemata are integrated upwards into a schema hierarchy which leads to a reduction of the complexity of the system and finally to a quasi-automatic execution of the task. However, parallel to this kind of upward integration the higher-order, schemata impose constraints upon the lower-level schemata. Such a hierarchy which upward integration and downward constraints is not decomposable in the sense of Simon (1965). If for a different task only some of the lower-level schemata are necessary, they cannot be easily separated from the schema hierarchy they are part of.

The postulation of downward constraints distinguishes this model from the notion of 'increasingly complex microworlds' (ICMs) as suggested by Burton, Brown, Fischer (1984) for learning how to ski downhill. It has been shown that in skiing integrated subskills are no longer available for transfer tasks if a high performance level has been accomplished (Leist, in press). This result contradicts the implicit assumption in the ICM-approach, namely, that ICMs can be used as interchangeable building blocks in skill acquisition. The consequences of decomposable vs. non-decomposable representations of motor skills have been investigated by Körndle (1983) and by Zimmer (1984). The general hypothesis of our experiments is that the described model of schema integration underlies the acquisition of skills. The practical consequence of this

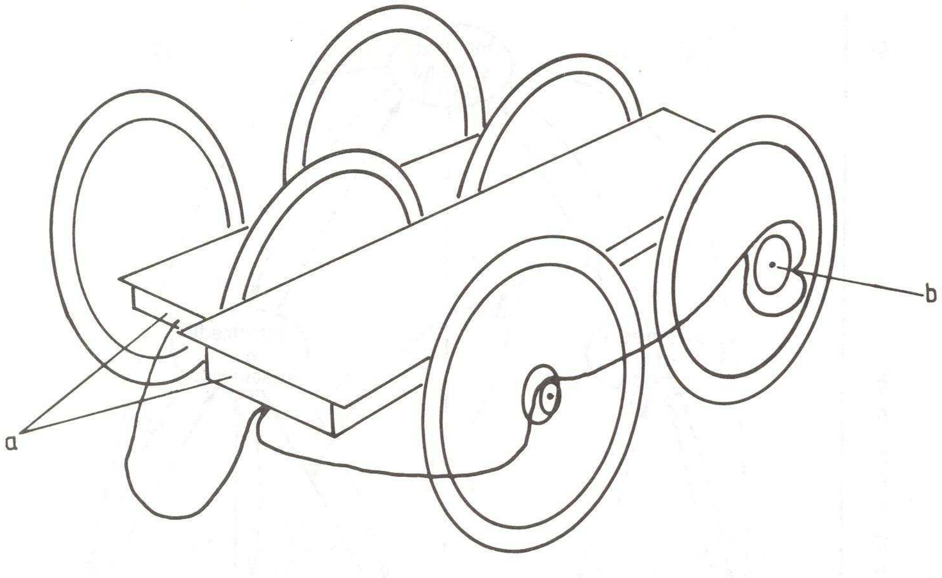


Figure 3: A Pedalo as used in the experiment with (a) two measuring devices for horizontal and vertical forces and (b) one for measuring the velocity.

model is that complete transfer from one task to another is only possible if both tasks are admissible transformations of the same schema. Partial transfer (i.e. some but not all subskills necessary for one task are necessary for the other) is only possible as long as the subskills are not integrated into the superordinate schema, that is, automatized.

This imputed mechanism has been investigated in an experiment where adults were taught to ride a Pedalo (an instrument resembling partially a bicycle which is used to train the sense of equilibrium in handicapped children).

The performance of the subjects has been measured by computing the difference between the velocity as prescribed by a metronome and the actual (observed) velocity. In Figure 4 this difference is given by the dotted area between the curve indicating the prescribed speed and the actual velocity of the Pedalo as produced by a subject.

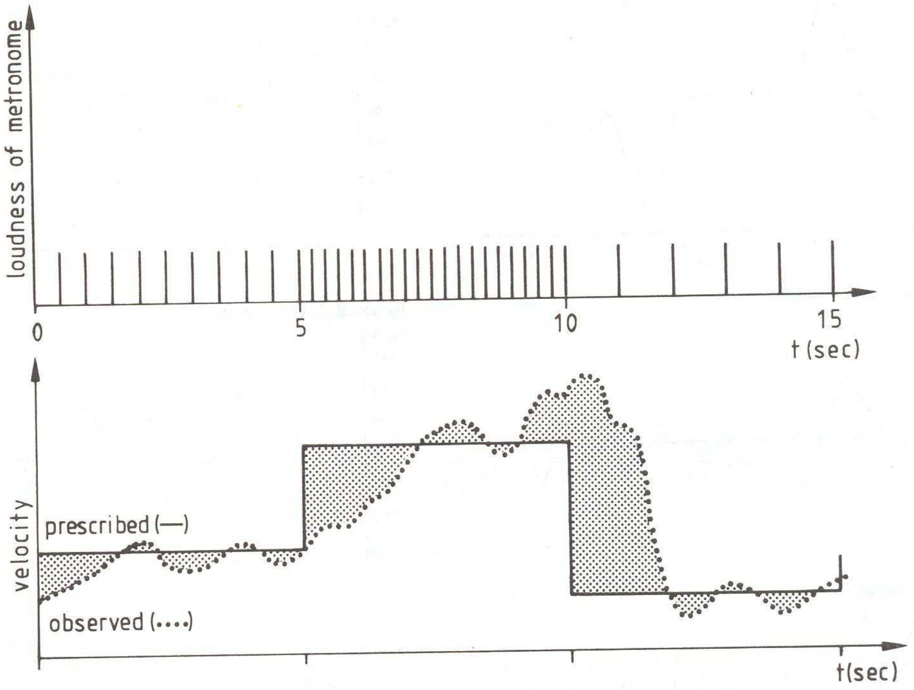
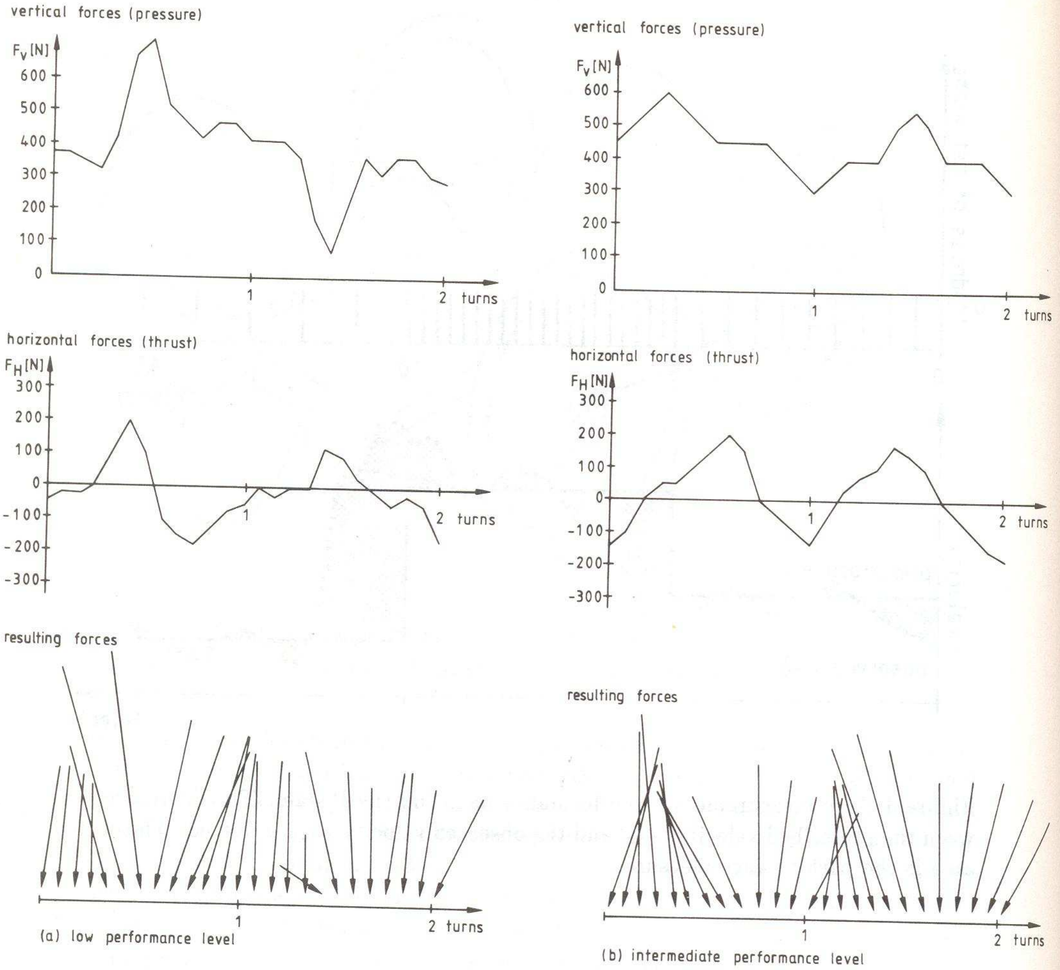


Figure 4: The measurement of performance in riding the Pedalo. The difference between the prescribed velocity (—) and the observed velocity (....) is dotted: The dotted area is the performance measure.



(a) low performance level

(b) intermediate performance level

Figure 5: (a) vertical, horizontal, and resulting forces in riding the Pedalo on a low performance level for two full turns of the wheels; (b) the same for an intermediate performance level, (c) the same for a high performance level. The length of the arrows indicates the amount of force, the angular orientation gives the direction.

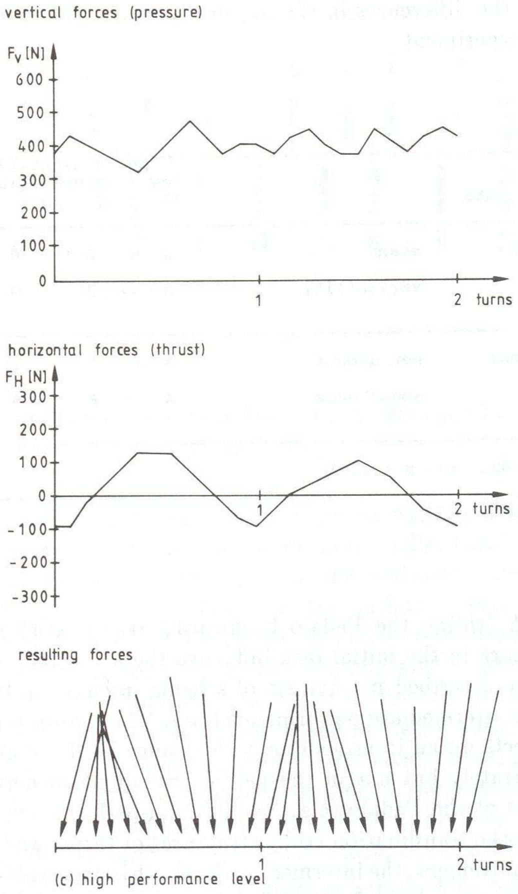


Figure 5 c: Legend see Figures 5 a & b.

A more detailed analysis of the motor action underlying this performance is possible by measuring the vertical forces (pressure), the horizontal forces (thrust) and the resulting forces. Typical examples for these data are shown in Figure 5 for a low level of performance (5a), for an intermediate level (5b) and for a high level (5c).

Table 1 shows a comparison of the physical data (effective forces and directional changes) on the different performance levels. It is immediately apparent that the performance levels are characterized by structurally different physical data and that these data make the conclusion necessary that the levels are *qualitatively* different.

The comparison of the effective forces on the different levels indicates that the acquisition of the skilled action is accompanied by an increasingly smooth flow of effective forces (i.e. small changes in the direction and strength). This is achieved by integrating the actions controlling thrust and pressure into one action of higher order.

Table 1: Testing the differences in the physical data for the three performance levels in the "Pedalo" experiment

		performance level					
physical data		low (A)		intermediate (B)			high (C)
effective	mean	A	≈	B	B	>>	C
forces	variability	A	>>	B	B	≈	C
directional	net amount	A	<	B	B	>	C
changes	smoothness	A	<<	B	B	<	C

<: $p < 0.05$, <<: $p < 0.01$

In a transfer task (riding the Pedalo backwards) it was studied how the different levels of performance in the initial task influence the acquisition of the new skill. As predicted from the described mechanism of schema integration the transfer was best for subjects on an intermediate performance level. The reason for this can be seen in Figure 5 b: Subjects on an intermediate performance level are able to control thrust and pressure separately but not in the perfect coordination necessary for a smooth forward movement of the Pedalo (e.g. on the high-performance level as depicted in Figure 5 c). Since the coordination (time structure) of thrust and pressure is different for the backward movement, the intermediate level subjects are able to utilize 'pressure' and 'thrust' as decomposable sub-skills (i.e. lower level schemata) in building up the new pattern of coordination, whereas the high performance subjects have to start the learning process anew.

The subjects' verbal reports on their coping with the task of riding the Pedalo are in line with the interpretation of the performance data. It turned out that on the intermediate stage the reports were highly detailed and consisted for the greater part of descriptions of perceptual and specific motor actions. However, on the final stage subjects reported only very global strategies (e.g. "I try to thrust").

This result indicates that the optimal timing for transfer is *before* the final stage of competence has been reached because on higher levels of competence the downward constraints impede the utilization of the sub-skills which are to be transferred from the initial task to the new task.

Similar qualitative differences in motor behavior on different performance levels have been observed by LEWIN (1926) in a phenomenological study. He describes skilled performance in typewriting as compared to search-and-hit typing as something only seemingly equivalent: "In reality, the typing of an expert typist is not a performance comparable to that of a beginner only more trained but something psychologically

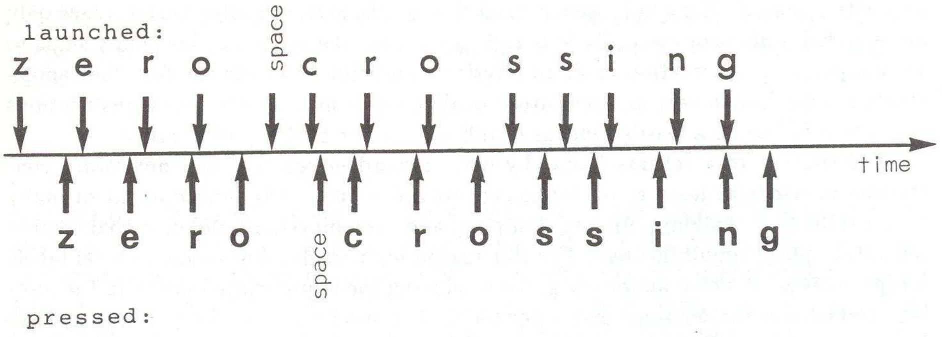


Figure 6: Time coordination of launching finger movements and hitting the keys of the typewriter (adapted from GENTNER et al. (1980))

different. ...(The searching for a key) has become an entirely dependent subprocess of the general performance...As well as the general (skilled) performance cannot be characterized as a kind of search, the typing of the beginner (cannot be reduzed) to finger lifting" (1926, p. 306/7, translation by the authors). HACKER (1978^2) refers to this phenomenological study of LEWIN in an attempt to corroborate his strictly unidirectional hierarchical model of VVR-units (comparable to MILLERS et al. (1960) TOTE units). However, such a undirectional structure fails to capture the very essence of skilled typewriting in comparison to search-and-hit techniques, namely, the simultaneous activity of the fingers. NORMAN and RUMELHART (1983, p. 47) describe this quite aptly as "...the movement of seagrass weaving in the waves ... all in motion at the same time." GENTNER, GRUDIN & CONWAY (1980) in their kinematic study of typewriting documents this parallel execution of movements (see Figure 6).

The fluent movements in skilled typewirting are achieved by decoupling the strictly sequential relation of the time structures for initiating and executing the key presses. Thereby the different complexity of finger movements (e.g. "t": moving the index finger on line up and one position to the right as compared to "s" where the ring finger remains in its 'home' position) can be taken care of by a differential initiating of movements, subsequently the resultant flow of key presses becomes more homogeneous.

This constant flow of movements corresponds to the description of skilled performance, namely, that 'it just feels right'. It should be noted that on this level of performance the stress (KOFFKA 1935) becomes minimal and therefore in skilled motor behavior a steady state is achieved with the consequence that the pattern of behavior is no longer influenced by external experience.

5 Motor Learning and the Language of Motor Experience

The qualitative changes in motor behavior on the different performance levels are accompanied by corresponding changes in the consciously accessible mental representations. This can be inferred from the verbal reports given by the subjects during the acquisition period. If it can be generalized that on the level of skilled performance only quite global evaluations (e.g. 'it feels right') exist for the subjects, this result helps to solve a puzzling observation made in physical education: Despite the fact that adolescents usually have a very differentiated vocabulary for movements, verbal instructions very often fail to be a feasible means of influencing the motor performance.

The concept of a schema hierarchy with upward integration and downward constraints provides at least a partial answer to this riddle: The development of many motor skills (e.g. walking, running, jumping, and even bicycling) and of verbal competence take place simultaneously. For this reason humans develop specific verbal labels for 'primitives' of motor actions (e.g. for producing the appropriate tension in the foot-leg combination for running) only *after* the higher order schemata (e.g. running) have been automatized. Earlier available verbal labels like 'jumping', 'running', etc. pertain to those higher-order schemata which resist decomposition because of the described mechanism in schema integration. In physical education (especially in the so called 'sensu-motor' approach (VOLPERT 1971) or in the ICM approach of BURTON, BROWN, FISCHER (1984)) one has attempted to circumvent the problem of an insufficient verbal repertory for motor actions by giving exact physical descriptions or depictions of the required movements. However, quite often this kind of instruction does not work because the physically correct descriptions do not fit into the frame of reference for sensory experiences of the students (e.g. there is no internal representation for 'about 10 centimeters above your head'). Furthermore, these instructions necessarily impose a sequential structure upon tasks which have to be performed in parallel. Schema theory suggests not to look for such exact verbal (or pictorial) descriptions but for higher order schemata for which experientially rich verbal labels exist and which are structurally equivalent to the new task. Of special importance is the time structure governing the parallel execution of sub-skills. One tool provided by language for this kind of a verbal modification of internal representations are analogies and metaphors (see e.g. ORTONY 1979; HOHNECK & HOFFMAN 1980; INDURKHYA 1987). VOLGER (1980) has developed a couple of instructional texts in metaphorical language (e.g. for learning down-hill skiing or swimming) and has shown the efficiency of this approach. The schema-theoretic analysis of this approach (ZIMMER, in preparation) reveals, that the strikingness of metaphors and their instructional efficiency is caused by imposing a novel constraint structure upon an established schema hierarchy. The concomitant changes in the admissible transformations of subsidiary schemata permit the recomposition of the timing and spacing of actions necessary for the motor regulation of the new skill.

6 Conclusion

The results of the reported experiments support the suggested model for the organization of motor skills according to which the acquisition process is characterized by the progressive integration of lower-level schemata into schema hierarchies. The different levels of performance correspond to levels of integration: starting from a mere collection of low-level schemata (sub-skills), a first level of integration is approached when independent sub-skills are roughly coordinated. On this stage the sub-skills are still available as building blocks (RUMELHART 1980) for alternative forms of coordination. However, if on the final level of integration downward constraints restrict the admissible transformations of lower-level schemata, the schema hierarchy is no longer decomposable and therefore its constituents cannot easily be utilized for alternative skills.

Abstract

Starting from a Gestalt theoretic framework of motor behavior, different theoretical approaches to motor skill acquisition are compared and analyzed in regard to their explanatory power for the phenomena of motor equivalence, variability, and complexity. It is suggested that a model of hierarchical schema integration (HSI) fits the Gestalt-theoretic framework and accounts best for the available empirical results. Two paradigmatic experiments are reported that test the assumptions of the HSI-model and show that changes in observable behavior are concomitant with qualitative changes in the representational structure governing them, as deduced from the verbal reports of the subjects. The HSI model is corroborated by the results. In conclusion, consequences are drawn from the HSI-model for the relations between the acquisition of motor skills and the possibility to talk about them or to integrate verbal information into them.

Zusammenfassung

Ausgehend von einem gestalttheoretischen Bezugsrahmen der Motorik werden unterschiedliche Theorieansätze motorischen Lernens verglichen und hinsichtlich ihrer Möglichkeit analysiert, die Phänomene der motorischen Äquivalenz, der Variabilität von Bewegungen und der Komplexität des motorischen Systems zu erklären. Als Lösungsansatz wird eine hierarchische Schema-Integration (HSI) vorgeschlagen, die dem gestalttheoretischen Bezugsrahmen entspricht und am besten die vorhandenen Befunde erklärt.

Anhand zweier paradigmatischer Experimente werden die mit diesem Lösungsansatz verbundenen Annahmen überprüft. Dabei kann gezeigt werden, daß Änderungen im motorischen Verhalten einhergehen mit qualitativen Änderungen in der durch Verbaldaten erfaßten Repräsentationsstruktur, die die Bewegungsproduktion steuert. Außerdem stützen die Daten die postulierte hierarchische Schema-Integration. Schließlich werden aus der HSI Folgerungen für den Zusammenhang von motorischem Lernen und der Möglichkeit abgeleitet, diese Prozesse zu verbalisieren bzw. diese Information in den Lernprozeß zu integrieren.

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