Title
The Role of Internal Representation in the Acquisition of Motor Skills

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The Rôle of Internal Representations in the Acquisition of Motor Skills

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The typical situation in the learning of complex motor skills can be described as follows: An observer transforms perceived or described motor actions into his or her innervation patterns which initiate and control a motor behavior similar to or identical with the observed or described motor action. The internal or external evaluation of this similarity then serves as feedback for the learning process.

In the tradition of psychology a couple of different approaches to the analysis of this situation can be ditinguished:

(i) the behavioristic approach (Greenwald & Albert, 1968; and especially Skinner, 1968, where the learning of 'high jump' is analyzed) which concentrates on the situational variables and the related reactions.

(ii) the systems approach (Bernstein, 1967; Adams, 1971) in which the regulatory process of motor activity is central, that is, the modification of actions depending on the comparison of observed results with internal or external criteria.

(iii) the internal-representations approach (Bartlett, 1932; Schmidt, 1975), the central assumption in this approach is that perceptual as well as regulatory processes are governed by internal models (e.g. schemata).

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

(i) motor equivalence,

(ii) the variability of motor behavior, and at last

(iii) the complexity of the motor system.

The behavioristic approach fails for any of these criteria. Therefore, its seemingly elegant solution of the representation problem, namely by simply skipping it, does not work. Bernstein's (1967) original approach and Schmidt's approach (1975) succeed only partially. Bernstein's systems-theoretic approach fails because the assumption of a rigid motor program is not sufficient even for very simple positioning tasks. Schmidt (1975) who overcomes these difficulties by introducing seperate recall and recognition schemata fails for the criterion of complextiy of the motor system because he does not take into account that the very characteristics of a movement change if this movement is integrated into a movement of higher complexity.

The schema-theoretic approach as suggested by Cassirer (1944) can be used to integrate the systems approach and the internal representation approach.

The concept of the schema is defined according to Cassirer (1944) as consisting of:

(i) a set of primitives which are not further analyzable in the given context,

(ii) a set of organizational rules which can be paralleled to Helmholtz' logic of unconscious inferences,

(iii) a set of admissible transformations, that is, transformations which define the class of invariants of the objects (here: motor patterns) in question.

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, that is, (i) and (ii), but that the set of admissible transformations of this skill has be taken into account too. This is in line with the behavioral effects of the ablation of the motor cortex (Pribram, 1971), that is, a break-down of complex motor skills without an impairment of particular muscle functions. Pribram (1971, p.14) concludes: "... behavioral acts, not muscles or movements, were encoded in the motor cortex."
In an experiment how to learn cutting the spin in table tennis I have investigated the influence of different instructional methods on the internal representations of a biomechanically identical motor pattern. The two instructional methods were (group I) 'learning the underlying physical principle' and 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 to the state of competence 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. speed of the ball etc.). However, in the end both 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 in the two experimental groups.

Insert Figure 1 about here

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 motor activities are completely different. Therefore it was expected that the internal representation of the task by means of a physical model would facilitate transfer. In contrast to this a purely motor or visukinesthetic 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 these subjects are 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 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.

Insert Figure 2 about here

In this graph schemata are integrated upwards into a schema hierarchy which leads to a reduction of the complexity of the system. However, parallel to this kind of upward integration the higher-order schemata impose constraints upon the lower-order schemata. Such a hierarchy with upward integration and downward constraints is not decomposable in the sense of Simon (1965).
The consequences of decomposable vs. non-decomposable representations of motor skills have been investigated by Körndle (1983) and by myself (in press). The underlying hypothesis of our experiment is that the described model of schema integration underlies the acquisition of skills. The practical consequence of this 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 sub-skills necessary for one task are necessary for the other) is only possible as long as the sub-skills are not integrated into the superordinate schema.

This imputed mechanism has been investigated in an experiment where children were taught to ride a Pedalo - an instrument resembling partially a bicycle which is used to train the sense of equilibrium in 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 3 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.

Insert Figure 3 about here

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 4 for a low degree of performance, a medium, and a high degree.

Insert Figure 4 about here

The comparison of the effective forces indicates that the acquisition of the skilled action is accompanied by an increasingly smooth flow of effective forces. This is achieved by integrating the actions controlling thrust and pressure into one action of higher order. 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 4 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. Since the coordination of thrust and pressure is different for the backward movement, the medium-level subjetcs are able to utilize 'pressure' and 'thrust' as 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 subject's 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 consistent for the greater part of descriptions of perceptual and specific motor actions, whereas on the final stage subjects reported only very global strategies (e.g. "I try to thrust").

The result indicates 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.

In conclusion, the results of the reported experiments support the suggested model for the internal representation 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 lower-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.

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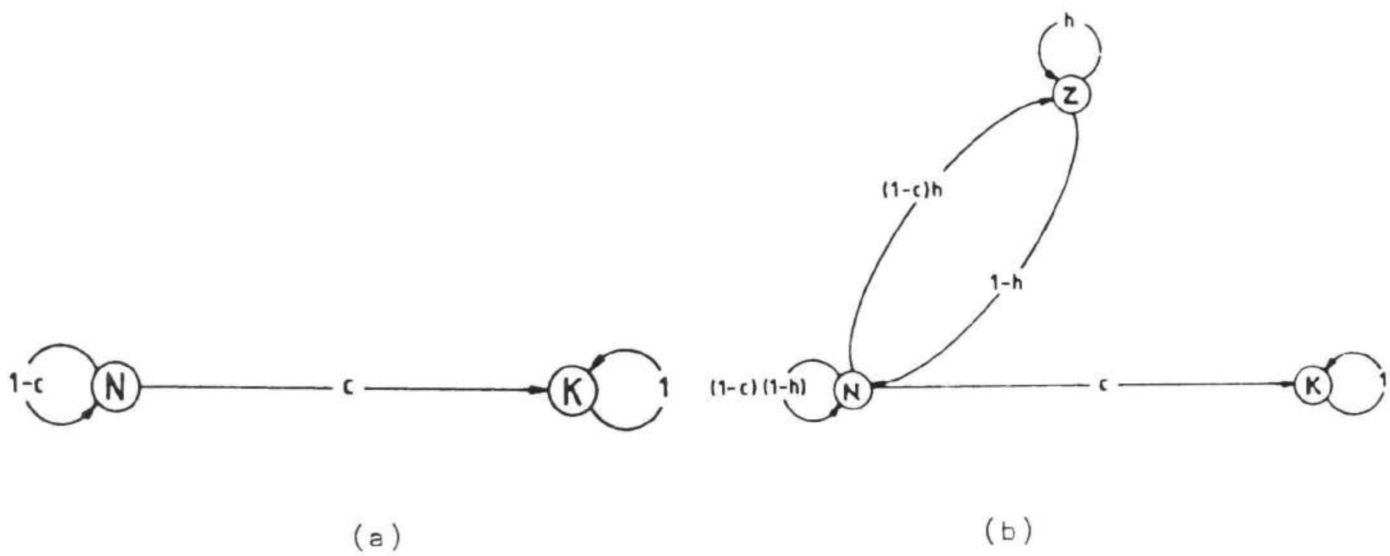
Figure Captions

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 representational state.
c,h,(1-c),1,(1-h),(1-c)h, and (1-c)(1-h) are the transition probabilities.

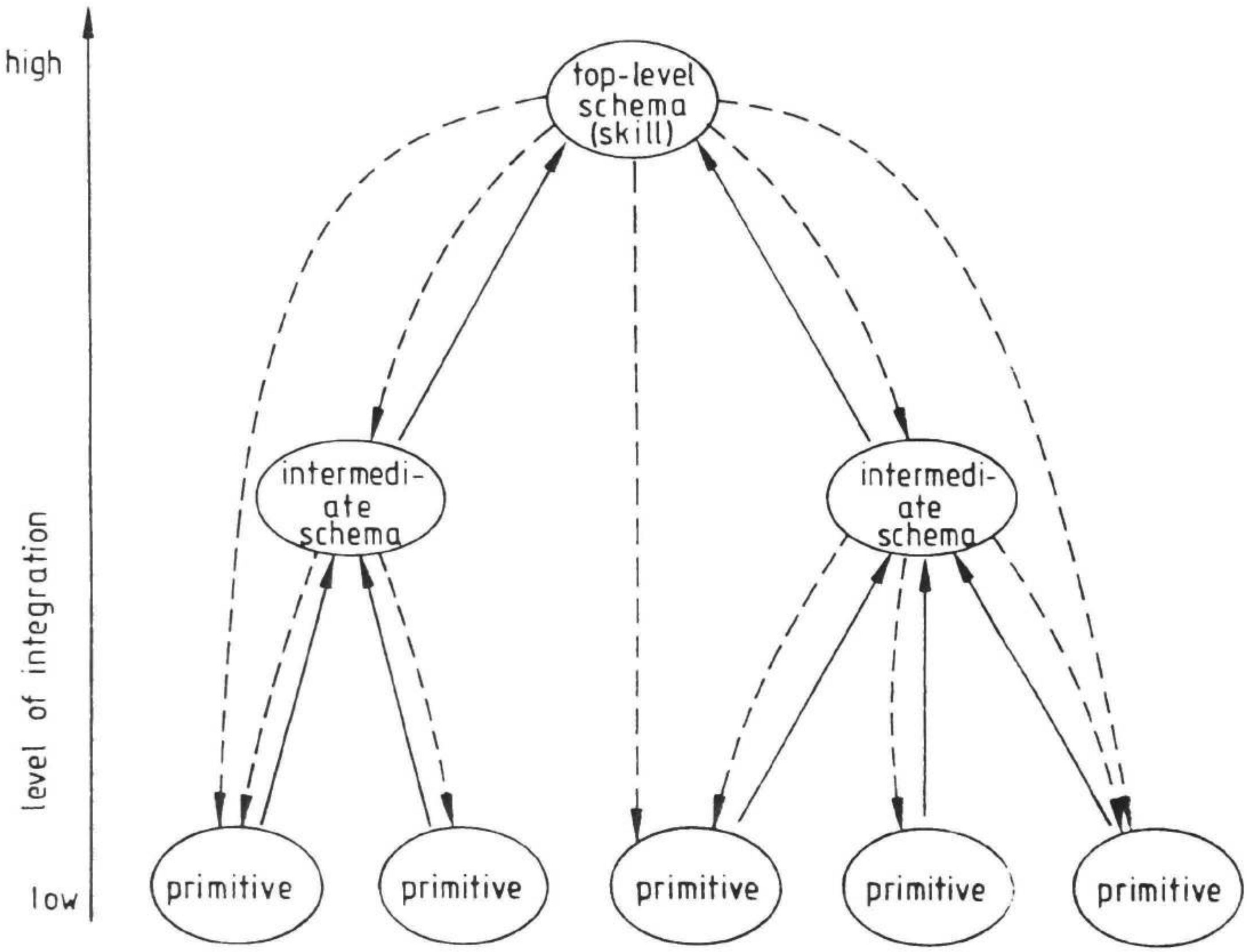
Figure 2: The model of schema integration (⟶) and downward constraints (⤷).

Figure 3: 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.

Figure 4: (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 inidicates the amount of force, the angular orientation gives the direction.



Figure


high
low
level of integration
top-level
schema
(skill)
intermedi-
ate
schema
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ate
schema
primitive
primitive
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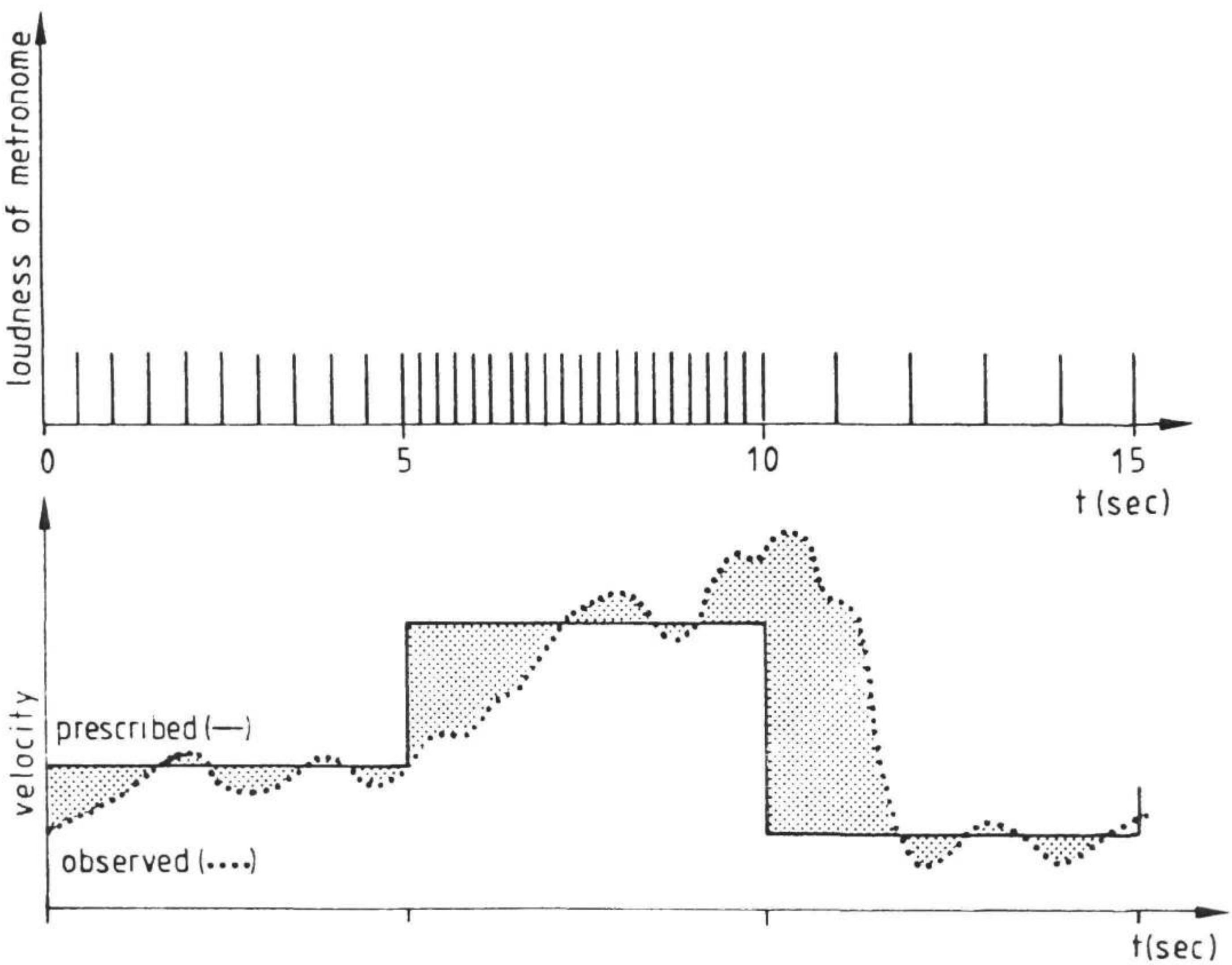
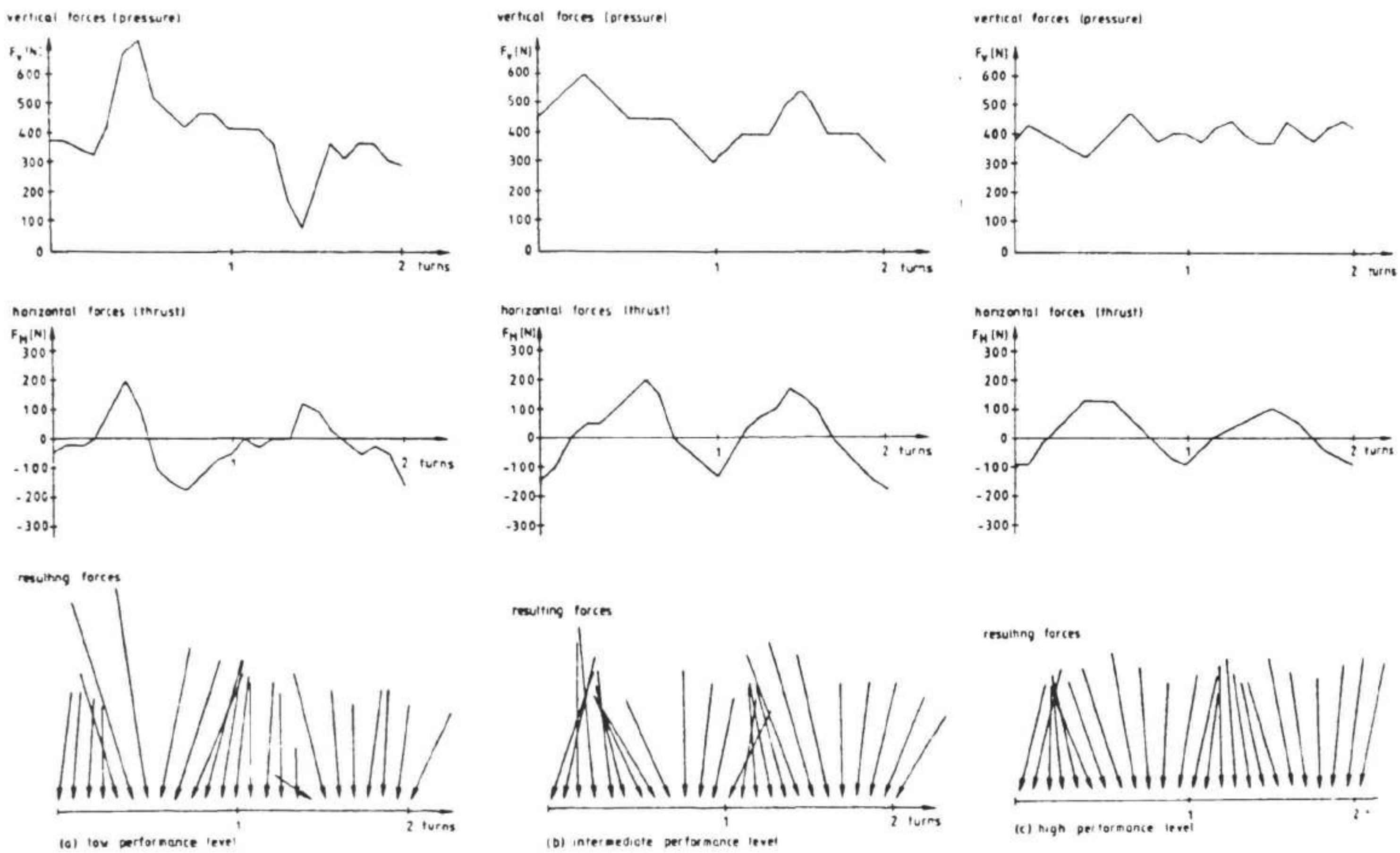

loudness of metronome
0
5
10
15
t (sec)
velocity
prescribed (—)
observed (....)
t(sec)

Figure 3



vertical forces (pressure)
F_V [N]
horizontal forces (thrust)
F_H [N]
turns
resulting forces
(a) low performance level
(b) intermediate performance level
(c) high performance level

Figure 4