DEFINING AND MEASURING PSYCHOMOTOR PERFORMANCE

By

Dr. OSSI AUTIO

University of Helsinki, Finland.

ABSTRACT

Psychomotor performance is fundamental to human existence. It is important in many real world activities and nowadays psychomotor tests are used in several fields of industry, army, and medical sciences in employee selection. This article tries to define psychomotor activity by introducing some psychomotor theories. Furthermore the interrelationship between psychomotor, cognitive, and affective area is researched. It seems that there occurs a significant correlation between psychomotor and cognitive area, but between psychomotor and affective tests only a small correlation was found.

INTRODUCTION

The acquisition of motor skills is fundamental to human existence. At each stage within the cycle of life, humans continuously strive to acquire new skills or to refine existing ones in the hope that productivity and quality of life is enhanced. Despite the fact that skilled behavior underlines almost every human activity, our understanding of the factors that contribute to attainment of expertise is far from complete.

The study of motor learning has a long history. There appears to be general consensus that the earliest formal study of motor skill acquisition can be traced to the work of Bryan and Harter (1887, 1889) on the sending and receiving of Morse code message. The work of Bryan and Harter was important as they studied real-world skill, compared expert and novice telegraphers and, in the later study they examined the learning curves of several operators for 40-weeks period.

The area of skill acquisition remained fairly dormant until the Second World War brought with it the need for the selection and training of military personnel and a renewed interest in the learning of motor skills. Tracking, involving the following of a target with a cursor, became an exemplary task for the study. It allowed for a detailed examination of eye-hand coordination, and a fundamental skill to many real world activities such as flying an aircraft, steering a boat or driving a car.

Later on E.A. Fleishman had great influence on the thinking of skill acquisition. The research on individual differences and learning was concerned with designing new motor tests to improve personnel selection in the US Air Force. Using a factor, analytic approach, Fleishman (1956) administered a battery of tasks measuring different skills to hundreds of participants, usually airmen, and examined patterns of correlations between the tasks.

The next step in psychomotor research was taxonomic models. These were offered as a way of viewing, explaining, and categorizing the components of the psychomotor domain. Taxonomic model was not a rigidly fixed conceptual model, but a flexible model capable of shrinking or expanding. It was a logical classification of movement experiences of the learner and it was consistent with accepted theories and principles of motor learning. The best known psychomotor taxonomies were those of Simpson (1966) and Harrow (1972), but soon they became old-fashioned, because it was commonly accepted, that in every psychomotor action there was an interrelationship between cognitive and psychomotor domain.

After these works there was a rapid change in experimental psychology and interest in skill learning declined as many psychologists became preoccupied with other topics more central to the upcoming "cognitive revolution". Still in the last forty years, researchers have gained enormous insight into the principles of high-level skilled performance. Nowadays psychomotor tests are used in several fields of industry, army and medical science. It is argued that new computer based assessment innovations provide a means toward revisiting psychomotor testing to augment employee selection batteries (Ackerman & al. 1999). Automated versions of some old psychomotor tests seem to be as predictive of military pilot/aviator performance today as in the past. The psychomotor tests receiving the most attention today are the Complex Coordination and Two-Hand Coordination tests (Griffin & al. 1996).

Oakes & al. (2004) have found that some personality factors positively correlate with skill acquisition and that skill acquisition can predict the level of subsequent job performance. This finding seems to have great importance in surgery, where different psychomotor tests have been developed for training and selection of surgeons (Gallagher & al. 2001; Harris & al. 1994; Hance & al. 2004).

There has been a rapid change in technology and it has had many effects on the research of psychomotor performance as well, but still according to Summers (2004) one of the problems inherent in the field of psychomotor domain has been agreeing on what we regard as a skilled behavior. Most agree that a perfectly executed sport accomplishment or skilled surgery is a highly valued psychomotor activity, but what is a simple motor action that few cannot achieve, like reaching for a glass is more contentious. The problem is that while the reach and grasp action is a simple automatic action for an adult, it poses a complex motor control problem for a young child. There are huge individual differences in abilities, personality, and motivation that should be considered when we try to define psychomotor activities.

Biesheuvel (1979) has noticed that psychomotor coordination and dexterity emerge broadly based on abilities involved in a wide range of industrial tasks. Proficiency in industrial tasks is predominantly the outcome of training and there is a strong case for the use of aptitude tests in developing countries to select candidates those who will respond most readily to such training. Nowadays, with the abrupt change of world economics, many big companies are moving to cheap labor markets in developing countries and many workers with technological proficiency need just simple psychomotor skills. If the direction of world economy stays like this, we have to take this demand seriously, because soon there will be strong need for simple psychomotor tests and training programs for individuals, likely to benefit from systematic training and practice.

Taxonomy of psychomotor operations

The best known psychomotor taxonomies are those of Simpson (1966) and Harrow (1972). The ideas of Simpson and Harrow offer some insight for the novice observer of the psychomotor domain, but to be honest both descriptions are too incomplete and inconsistent to serve as important educational and psychological references. Although they have been criticized later (Holcomb 1975); they have been cited for almost 40-years as a significant starting point in psychomotor research, so they must have had special merits in their time.

Simpson's taxonomy was among the first such efforts in the psychomotor domain. Her work has merit, but it utilizes a confusing and inconsistent terminology which mixes perceptual and movement references, thereby this psychomotor activity results in confusing cognitive operations. Certainly perceptual operations and motor operations are intimately related, but the coincident use of such terms as “guided response” and “complex overt response” creates an unnecessary duality of reference points for the user of the taxonomy. Thus the reader of her taxonomy is confronted with the problem of distinguishing process from product.

The process / product duality of Simpson's taxonomy can lead to a demonstration of interrelationship of cognitive and psychomotor domains. She lists perception as a psychomotor operation. However it can be argued that perception is a cognitive activity. If one accepts Guilford's (1979) view that one form of intelligence is the cognition of figural information, it can be concluded that, since perception is the cognition of figural information, perception must then be a form of concrete intelligence. These two points of view, perception as a psychomotor operation and perception as a cognitive activity, can therefore be seen to have considerable commonality. Rather than belonging solely to one domain or the other, they demonstrate the interdependence of the cognitive and psychomotor domains.

Harrow's taxonomy has mixed orientation to process and product similar to that of Simpson. Also, she considers “perceptual abilities” and “physical abilities” as discrete levels of her six-tiered classification. These underlying abilities are psychophysical variables of performance which are present at virtually all levels of activity. Both perception and physical abilities, as she uses the terms, are contributors to, and are enhanced by, nearly all psychomotor operations. Therefore, their treatment as separate levels reduces the clarity of her categorization. Her taxonomy is, in short, a little bit problematic which is of limited use to motor learning specialists.

As Holcomb (1975) argues we can agree that review of these taxonomies reveal the need for further clarification of psychomotor activity. Also, an improved taxonomy should describe psychomotor operations with reference to four primary areas of concern to motor activity educators: 1) the developmental process of the acquisition of general motor patterns, 2) the sequential operations of learning of specific motor skills, 3) psychomotor activity forms, or operational possibilities available to the mature performer, and 4) the interrelationship between cognitive and psychomotor domain.

Simpson (1966)	Harrow (1972)
1.0 Perception Awareness of objects and relations through the sensory modalities	1.0 Reflex movements
2.0 Set-preparatory Readiness for performance	2.0 Basic fundamental movements
3.0 Guided response Performance under the direction of instructor	3.0 Perceptual abilities Kinesthetic, visual, auditory, tactile and coordination abilities
4.0 Mechanism Habituation of a learned motor response	4.0 Physical abilities Endurance, strength, flexibility, agility, reaction time, dexterity
5.0 Complex overt response	5.0 Skilled movements
6.0 Adaptation	6.0 Non-discursive communication Non-verbal communication through movement

Table 1. Comparison of the Simpson and Harrow taxonomies of psychomotor domain

The classification of motor skills

Much on what is known today about the categorization of human skills, at least that which is based on empirical research, comes from correlation and factor analysis studies. Such correlation studies are typically carried out in the psychometric tradition, and little attempts have been made to integrate the ability concepts developed there into the more general body of psychological theory. Fleishman's (1954, 1972) systematic research on the structure of motor abilities has lead upon the construction of the motor hierarchy shown in figure 1, which is here summarized by (Powell & al. 1978).

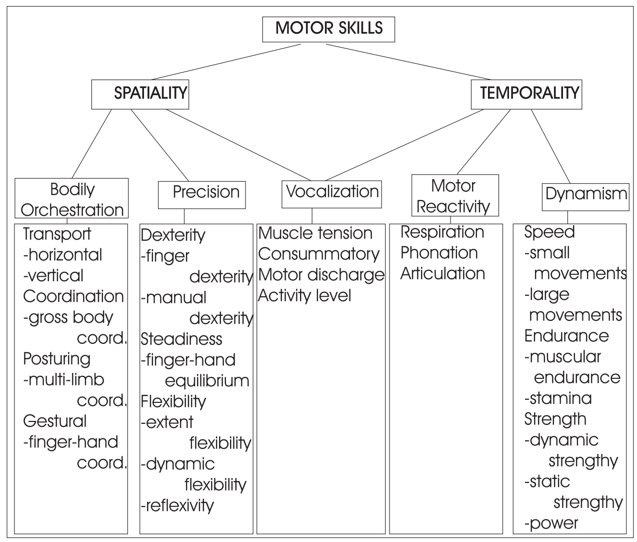

Figure 1. The hierarchical factor system of motor skills modified from (Powell & al. 1978).

Spatiality and temporality

These factors describe the most abstract dimensions of individual differences in motor functioning. Spatiality characterizes a broad class of motor functions and decomposable motor programs or parametric components which relate principally to the organization of behavior through space. The cognitive and motor processing involved in the programming of spatially-oriented motor functions involves relatively greater simultaneous processing and the right hemisphere of the cerebral cortex. On the other hand, temporality characterizes the broad class of motor functions and motor programs or parameters which relate primarily to the organization of behavior through time. The processing involved in temporally-oriented behaviors involves relatively greater emphasis upon sequential processing and the left hemisphere of the cerebral cortex.

Bodily orchestration

This refers to the dimensions underlying bodily movements which are typically involved in nonverbal communication. As such, it refers to the interactive organization of the body with respect to its general orientation (posturing). Posturing or the spatiotemporal positioning of the body, gesturing or the emphatic movement of the hands and limbs, and reactive emphasis or the emphatic movements of the facial muscles, have emerged from a variety of studies as important and relatively independent neuromuscular systems for nonverbal communication. In technical meaning bodily orchestration can also be related to coordination and transport. Transport refers to the general movement of the body, or parts of the body, through three dimensional spaces. Transport is postulated to be decomposable into the three components of horizontal movement, vertical movement, and general mobility which is further divided into gross body coordination and multi limb coordination.

Precision

This could probably be described as the "coordination" of movements, or in some situations by term articulation. However, coordination is involved in all integrated movements, and articulation is more appropriately reserved for characterizing an important dimension of motor speech. Furthermore coordination has technical meaning in systems theory, referring to the intervention, or inputs, from control-decision units of multilevel systems. Precision, in turn, subsumes the next order factors of equilibrium (ability to maintain balance and steadiness), impulsion (general reactivity of the body to changing conditions), flexibility (the ability to make adjustments and modifications in graded or discrete movements), and dexterity (the precision of small movements).

Vocalization

This factor refers specifically to motor speech and has probably been the subject of more experimental investigations than any other factors of the motor hierarchy. Of course vocalization is not generally dealt with under the rubric of motor skills, but this relates more to the extant divisions of academic disciplines than any meaningful characteristics of the structure of motor system.

Motor reactivity

This factor dimension has been suggested from the results of factor analytic investigations of emotionality. Although the relevant studies have not been conducted on emotionality in appetitive situations, it is postulated that there is a consummator factor which characterizes a variety of specific behaviors from aggressive attack to heart beat. Factors subsumed by motor reactivity are, in general, closely related to autonomic processes. In the next factor level motor reactivity is divided into muscle tension, consummator, motor discharge, and activity level.

Dynamism

It characterizes the common aspects of the physical proficiency dimensions related to the energetic components of skilled sequences. The next level factors subsumed by dynamism represent abstractions of the commonalities among the physical proficiency abilities and they are named: speed, endurance, and strength. Speed is further divided into small movements (rapid movements of distal muscular groups, or simply wrist, finger speed), and large movements (rapid movements of gross body parts without an accuracy constraint). Endurance is divided into muscular endurance (the capacity of large muscle groups to perform over extended periods of time without experienced fatigue), and stamina (exertion of maximum effort over relatively long periods of time). Strength is divided into dynamic strength (exertion of continuous or repeated forceful movements of the limbs over relatively long period of time), static strength (exertion of maximum force against external objectives for brief period of time, which is best exemplified as by lifting weights), and power (exertion of strength against large objects and gravity in general, it relates to the overall strength of the body).

The theory of motor performance

There has been much interest in constructing theoretical conceptions of the dynamics of human performance. However, the analysis of motor abilities suggests that any process description is more complex than has yet been explicitly admitted. First, such descriptions must be more complex because of the large number and the wide range of dimensions that are needed in order to fully characterize individual difference in the motor domain.According to Powell & al. (1978) there are several compatible ways of describing the varied structural components of the motor system identified in Figure 2. From the standpoint of factor analysis, they represent hierarchically organized dimensions of individual differences; from the viewpoint of information processing theory, they represent decomposable classes of general motor programs or classes of parameters entailed by those programs, and from the perspective of general systems theory, they can be construed as hierarchically decomposable systems and subsystems.

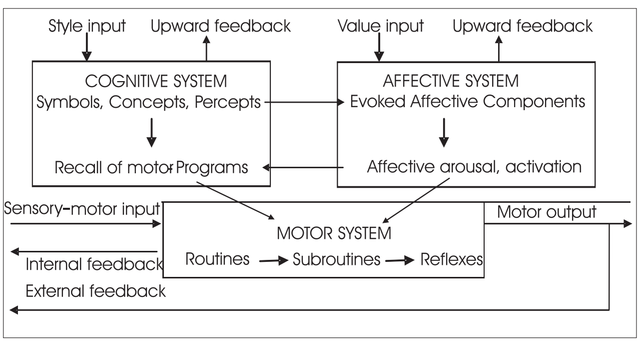

Figure 2. Overall relations among the cognitive, affective, and motor systems in motor performance (Powell & al. 1978).

The second way in which a theory of motor performance must be complex is in terms of system interactions and integrations. For example, while recent theorizing within the motor domain has focused on cognitive decision processes with respect to skilled performance, the role of affective processes has been ignored. And on the other side of the coin, theorizing with respect to the role of affective processes in motor performance has ignored the integral role of cognitive processes. Finally, although cognitive decision processes play an integral role in motor performance, there are psychological processes within the motor system itself which must be further explored.

The critical idea behind the motor performance is that there exists, or is reconstructed, some central representation of the movements to be made in either complex or simple behavioral sequences. This does not mean that feedback is not part of central representation and is unimportant in controlling sequences of movement, for clearly it does play a critical role in most situations. However, priority of control-decision is given over the central processes which, in effect, determine the role that peripheral feedback is to play.

From the overall relationship among the cognitive, affective, and motor system: it can be seen that the principal role of the cognitive system with respect to motor functioning is in the organization of motor programs. Affective processes play a critical role in determining what specific behaviors we engage in as well as the resulting observable characteristics of those behaviors. Affective processes also interfere with some behavioral performances while facilitating other systems.

Most of the important integrated sequences of behavior in which we engage require that affective processes be reflected in the general flow of behavior. In this regard it is postulated that cognitive and affective processes interact both directly and indirectly with the motor system. The direct cognitive-motor linkage involves the construction or reconstruction of motor programs, while the direct affective-motor linkage involves the activation of specific motor processes or intervention into ongoing programs.

The cognitive system interacts indirectly with the motor system when particular percepts, concepts, or symbols evoke special affective processes. The affective components produce affective arousal or inhibition which, in turn, activate or disengage special motor processes. The whole interaction process of cognitive, affective and motor systems can be seen in figure 2.

Empirical study

The main problem from the conception stage of the study was - how to define psychomotor ability and how it can be measured in a way that would be simple, easy to use with large groups, and still be reliable and valid enough to be generalized to other student populations. In the test the effect of other areas of human personality (cognitive and affective domain) should also be taken into account, because it is almost impossible to separate the dimensions; in every psychomotor exercise there is a lot of cognitive thinking involved and in every cognitive act the affective domain is prominent.

The test of motor skills was called X-boxes (figure 3.) and it is based on the theory of Powell & al. 1978. In the test of motor skills all the elements of bodily orchestration, precision, and dynamism were involved. The instrument has originally been developed by Finnish ministry of labour and it is quite cheap compared to the computer based psychomotor tests. Besides that it is easy to use with large groups. The reliability of this test was 0.819 as measured with the Cronbach alpha.

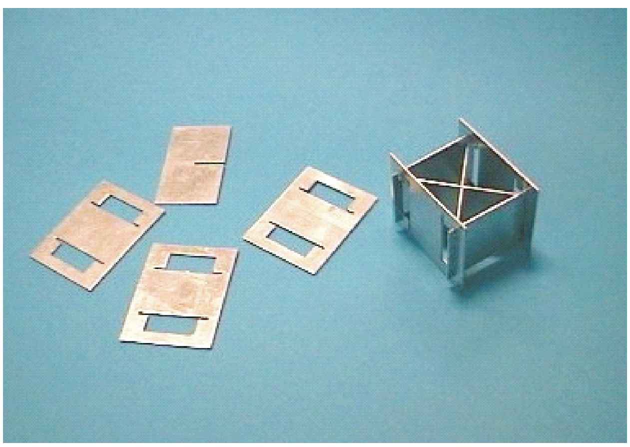

Figure 3. The test of psychomotor area called "x-boxes".

In the cognitive area the test instrument was called 'a test of technical thinking'. The test deals with physical laws, which can be observed in simple machines. Affective area was measured with a questionnaire of 14 items related to pupils 'attitudes towards technology'.

The research challenge was to measure how students' psychomotor abilities develop in Finnish comprehensive schools during grades 5 - 9, and are there any differences between boys and girls. Besides that we were interested to know, what the role of cognitive and affective area in psychomotor performance is. Two measurements were analyzed in each experiment groups in two years, i.e. 5.-7grades and 7.-9grades.

Results

The results show that in the psychomotor area students improve their performance quite a lot during their comprehensive school technology education. Significant improvement ($p < 0.001$) was found in both boys and girls of experiment groups. Figure 4 shows how psychomotor development increases from one grade level to the next.

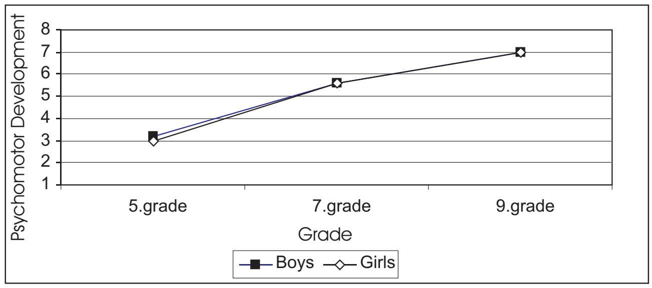

Figure 4. Development of Psychomotor Skills ($n = 267$, $p < 0.001$)

Differences from one grade level to the other were also significant ($p < 0.001$), i.e., between children in grade five versus those in grades seven and between grades seven and nine. Between boys and girls only small difference occurred in 5th grade experiment group, but the difference between groups was not statistically significant, although there was wider range of different materials in textile craft and motor skills which got emphasized more than technological knowledge. For most of the boys who attended the technology education classes, their technological concepts were more emphasized than just motor skills. The same result was actually found in Autio & Hansen (2002) between technology education and general craft education groups.

The research design did not control, for normal maturation so it is not possible to state unequivocally that only psychomotor development caused these achievement levels. On the other hand Autio (1997) has found out that the development in cognitive area was in a different direction. So it seems that students excel at psychomotor activities, perhaps because they see meaning in their accomplishment, even with small amount of practice. In the cognitive area the development is not so rapid in the beginning and it needs more time to achieve good results.

To find out what is the interrelationship between psychomotor, cognitive, and affective area we used the same research material as Autio (1997). In this research we made some correlation tests between psychomotor, cognitive, and affective area and found out that there was a certain correlation between psychomotor and cognitive area as already Kleine (1982) has suggested. Between psychomotor and affective tests only one significant correlation was found among the experiment groups.

		Cognitive area	Affective area	Significance
Psychomotor area (5.-7. Grade) N = 267/251	1.test 2.test	0.39 ** 0.34**	0.08 0.17**	r =.12, p=.05 r =.16, p=.01
Psychomotor area (5. grade) N = 113 / 104	1.test 2.test	0.43** 0.38**	0.07 0.16	r =.19, p=.05 r =.25, p=.01
Psychomotor area (7. grade) N = 154 / 147	1.test 2.test	0.23** 0.26**	0.10 0.18*	r =.16, p=.05 r =.21, p=.01
Psychomotor area (5. grade/ boys) N = 45/39	1.test 2.test	0.49*** 0.68***	0.01 0.24	r =.25, p=.05 r =.30, p=.01
Psychomotor area (5. grade / girls) N = 45/39	1.test 2.test	0.29* 0.05	0.09 0.14	r =.29, p=.05 r =.38, p=.01
Psychomotor area (7.grade / boys) N = 93/88	1.test 2.test	0.17 0.33**	0.12 0.35**	r =.21, p=.05 r =.27, p=.01
Psychomotor area (7.grade / girls) N = 61/59	1.test 2.test	0.36** 0.25*	0.10 0.05	r =.25, p=.05 r =.33, p=.01

Table 2. Correlation between psychomotor, cognitive, and affective area in boys and girls experiment groups.

Between psychomotor and cognitive area there was a significance correlation in almost every experiment group. The correlation in whole test group (n=267) was 0.39** in the first measurement and 0.35** in the second measurement. The correlation was higher in the 5thgrade experiment group in both measurements than in the 7thgrade group. The highest correlation between psychomotor and cognitive area was found in the 5thgrade boys group (0.49*** in the first and 0.68*** in the second measurement) and the lowest correlation was in the 7thgrade boys group (0.17) in the first measurement and 0.33 in the second measurement and in the 5thgrade girls group (0.05) in the second measurement, compared to 0.29 in the first measurement.

Between psychomotor and affective area there was no statistically significant correlation in the first measurement, but in the second measurement there occurred one significant correlation in the 7thgrade boys experiment group (0.35**). Hence, in the second measurement significant correlation was found also in the whole test group (0.17**) and in the 7thgrade test group (0.18*). The low level of correlation between psychomotor and affective area can be explained because, if we think of Powell & al. (1978) theory, the aptitude test used in these measurements was not directly designed to that purpose. But interestingly the only significant correlation among experiment groups occurred in the 7th grade boys test group, which had the best results in psychomotor ability test overall.

In the next step we tried to imitate the research design of Gallagher & al. (2001), in which novice and expert surgeons were compared. In our research we divided the whole experiment group into four groups. The first quarter (25%) consisted of those who performed best in the psychomotor ability test, and respectively the fourth quarter (25%) consisted of those who performed worst in the test. Besides that we divided the whole test group in two halves and tried to find out if the correlation is different in these groups.

Interestingly we found out that the correlation between psychomotor and cognitive area was highest (0.26* in the first test and 0.24* in the second test) in the group which performed worst in the psychomotor ability test overall. Hence, the same findings occurred in the group of the worst 50 % performers and the correlation was 0.39** in the first measurement and 0.38** in the second measurement. In other quarters no significant correlation between psychomotor and cognitive area was found.

Between psychomotor and affective area only one significant correlation was found. It occurred in the second measurement in the group of worst 50 % performers. Interestingly the highest but not significant correlation (0.21) in the quarter groups was found in the

		Cognitive area	Affective area	Significance
Psychomotor area (all) N = 267/251	1.test 2.test	0.39 ** 0.35**	0.08 0.17**	r =.12, p=.05 r =.16, p=.01
Psychomotor area (worst 50%) N = 135 / 130	1.test 2.test	0.39** 0.38**	0.11 0.18*	r =.17, p=.05 r =.23, p=.01
Psychomotor area (best 50%) N = 132 / 121	1.test 2.test	0.08 0.18*	0.06 0.15	r =.17, p=.05 r =.23, p=.01
Psychomotor area (worst 25 %) N = 70/67	1.test 2.test	0.26* 0.24*	0.15 0.07	r =.24, p=.05 r =.32, p=.01
Psychomotor area (next 25%) N = 65/63	1.test 2.test	0.00* 0.18	-0.02 0.06	r =.25, p=.05 r =.33, p=.01
Psychomotor area (next 25%) N = 65/62	1.test 2.test	0.05 0.03	-0.06 0.12	r =.25, p=.05 r =.33, p=.01
Psychomotor area (best 25%) N = 67/59	1.test 2.test	0.05 0.11	0.20 0.21	r =.25, p=.05 r =.33, p=.01

Table 3. Correlation between psychomotor, cognitive, and affective area in the experiment groups of best and worst performers in the psychomotor ability test.

group of best 25 % performers. This correlates with the earlier finding where the only significant correlation between psychomotor and affective area among experiment groups occurred in the 7^{th} grade boys test group, which had the best results in psychomotor ability test overall.

Discussion

The research of psychomotor performance has a long and rich history. Several meritorious researchers in past over hundred years have tried to find out the initial nature of psychomotor performance. Hundreds of theories have been created, but still the secret of the ideal psychomotor theory which covers the skilled movements of a sportsman and simple actions of a young child seems to be hidden.

Chaiken & al. (2000) conclude that initial psychomotor skill is constrained by working-memory limits. Practiced psychomotor skill is additionally limited by processing speed. This ability however is not due to a superior memory capacity, but rather to use strategies such as chunking to encode information into large meaningful units (Summers 2004). It has also been assumed that in skilled performance requiring fast reactions skilled performers have developed an ability to recognize advanced cues in the environment allowing for anticipation of what will happen next and thereby reducing processing time (Williams & al. 1999).

In this research we found out that the correlation between psychomotor and cognitive area seems to be an important factor. Interestingly the correlation between psychomotor and cognitive area was highest in the group of those who performed worst in the test of psychomotor ability. Instead the highest correlation between psychomotor and affective area was found among those who performed best in the psychomotor test.

Perhaps it can be assumed that in the first level of skill acquisition the cognitive area is dominant, and in the automated level of skilled performance the affective area has more importance. This corroborates with earlier research; according to Summers (2004) the learner moves through three general phases in the learning of a skill. In the early or cognitive stage the learner attempts to understand the task requirements through watching someone perform the skill and verbal instructions. Performance is quite variable during this phase as the learner tries out different performance strategies. In the intermediate or associative stage, the movement patterns are refined, errors are reduced and verbal mediation of movements is diminished. This stage can last for varying periods of time depending on the complexity of the skill to be learned and the adoption of optimal practice conditions for skill acquisition. The final or autonomous phase is achieved after extensive practice and is characterized by the performance of the skill with minimal mental effort (i.e. Automatically).

In spite of the limited resources it seems that we found out some evidence about the fascinating interrelationship between psychomotor and cognitive acts but still we have a long way to go in the search of the origin of the psychomotor performance. We are continuing our efforts in several related projects.

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ABOUT THE AUTHOR

Dr. Ossi Autio is a Senior Lecturer in Technology Education at the University of Helsinki. Since 1982, he has been working as a teacher in technology education. He has written textbooks and guidebooks for teachers. His main research interests are students' technical abilities and practical solutions of creative problem solving in Technology Education.