THE INFLUENCE OF CHOSEN ASPECTS OF CO-ORDINATION ON MOTOR LEARNING EFFICIENCY

by

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After many years of investigations the question how to coordinate and control successfully new movements is still one of the most challenging problems in movement science. Among many unsolved problems, describing determinants and predicting a result of motor learning occur as a basic one. The main objective of this work was to establish the efficiency of learning of different motor tasks and describing abilities, which allow to posses the high efficiency of that process. The research was conducted on 11 male subjects aged from 20 to 23. Subjects learned three different motor tasks. First, subjects learned to balance on a stabilometer. Then, they learned a 2-dimensional tracking task performed on a computer monitor by means of the “Hand Coordination Test” (2HAND). Finally, on the third stage of experiment, “Three-Dimensional Point Tracking” Test (3PTR) was used to establish the efficiency of learning fine motor movements performed in 3D virtual space. The learning procedure in all cases consisted from 30 to 48 blocked repetitions of a single task. Measurements of coordinative abilities were provided using procedures of the Vienna Test System (Dr Schuhfried GmbH) and stabilometer. Analysis of correlation and backward stepwise regression were the main statistical methods used in this work. The results did not prove the existing in literature (Blume 1981) theory that all coordinative abilities influence motor learning processes. These relations are dependant on performed motor task. Simultaneously it was stated in conclusions that the future development of research in the area of motor control and learning is possible only as a result of improved diagnostic tools to penetrate different human abilities, which underlie these phenomena.

Key words: co-ordination, human abilities, motor learning

Introduction

Learning a new motor skill – from a dynamical systems perspectives - is generally viewed as the transition from one particular dynamical state to another. It used to be described at two levels (dynamics) – one nested within the

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other. The first one is associated with the control structure assembled for producing the action – the coordinative structure or task-specific assembly of an effectors system. Second, the learning dynamic is intentional in that a future goal state determines the changes it undergoes (Fowler, Turvey 1978; Beek, van Santvoord 1992; Schmidt, Fitzpatrick 1993). The consequence of this learning dynamic is that information about this optimization process becomes available in the perceptual-motor workspace, including information about the learning dynamic's attractor – the optimal organization of the action system controls structure. It means that future state of the system determines its earlier action and learning process. Considering that aspect, it looks that precise knowledge of what is being learned should precede attempts to come to terms with questions as to how learning takes place. However control of complex motor actions and learning of that process depends on the interplay between organism, environment and task specific factors, yet the human abilities should be analyzed first (Newell 1986). One of the earliest views about human abilities was that a singular, global ability exists as a basis for all skill performance (Brace 1927). An opposite theory was proposed by Henry (1961) who stated, that movement behaviors are based on a large number of independent abilities. Despite methodological differences among co-existing theories a group of abilities playing a special role in the processes of motor control and learning is a general acknowledgement. These abilities were identified and named in a different way by scientists: Fleishman (1964) proposed to distinguish "perceptual-motor abilities", Gundlach (1968) suggested to consider "coordinative abilities" while Keele et al. (1985) identified "general co-ordination factors".

The notion that motor behavior depends on human abilities, determines the aim of this study which was to answer the following questions: Is the effect of motor learning of different tasks determined by the same factors? What abilities should you possess to learn different movements with high efficiency? Is it possible to predict results of the learning process?

The experiment was conducted on 11 men aged 22,3±1,6 years. The subjects had no documented motor or neurological disorders. Written consent from subjects was taken. The measurements were conducted in the Laboratory of the Department of Motor Control at the Academy of Physical Education in Katowice.

All subjects learned three different motor tasks. First, subjects learned to balance on a stabilometer having the axis of turning between the feet (balancing in the frontal plane). The stabilometer was connected with a computer, which was steering the measuring process. Two parameters were used in further analysis: the integral of deviation's module in degrees (INTEGRAL) and amount of changes of platform's movement direction (CHANGES). The learning procedure consisted of 30 repetitions of balancing skill on the platform (max. inclination – 13 degrees with the accuracy set at 0,001 degree). One repetition lasted 30 s and they were massed (5 trials in a block). The pause between each trial in one block lasted 15 s. The rest periods between blocks were 2 minutes long.

The day after learning the balancing task, subjects learned a 2-dimensional tracking task performed on a computer monitor by means of the "Hand Coordination Test" (2HAND) made by Schuhfried GmbH (Austria, Moedling). That procedure is a part of the Vienna Test System (VST) – computer-assisted physio-psychological testing procedures for clinical and research applications. 2HAND is focused on two components of performance: sensorimotor co-ordination between the eye and the hand and between the left hand and the right hand. The subject was instructed to move a light dot along a given path by means of two joysticks during the testing procedure. This path (whose width is adjustable) consisted of three sections making different demands on co-ordination of the left hand and the right hand. The point was being moved from the right to the left. Scoring was based on the following variables: mean time taken for the total path (TIME) and % error time (ERROR) - the ratio of total error time to total time. Second variable indicates the precision with which the co-ordination task is performed. The learning schedule consisted from 40 repetitions of tracking on the same path. Repetitions were blocked (4 trials in a block). The pause between each trial in one block lasted 5s. The rest periods between blocks were 2 minutes long.

On the third stage of the experiment, the “Three-Dimensional Point Tracking” Test (3PTR) was used to establish the efficiency of learning fine motor movements performed in 3D virtual space. It was the procedure using an apparatus and computer program from the VST. The 3PTR test was used for evaluating of sensorimotor, bimanual coordination at given working speed (visual information relating to direction, size and speed must be translated into adequate motor control action). A target symbol (square) of changing size that moved along tracks of varying difficulty, had to be pursued as precisely as possible by means of a tracking pointer (cross), which was steered with one joystick (XY parameter) and changed in size with another (Z). Two variables to evaluate bimanual coordination were considered: mean deviation SDXY and SDZ. The variables SD was obtained using the following formula for computation:

$$SD= \text{root } (1/N^* \text{ sum of } e_i \text{ squares})$$

e_i – deviation (in pixels) of the tracking co-ordinate from the target co-ordinate at sampling time i

N – total number of samplings

For the variable SDXY the deviation ei was recorded as XY-combined values:

$$e_i= \text{root } ((X_i-x_i)^2+(Y_i-y_i)^2)$$

The variables SDXY and SDZ were regarded as the best global indicators of tracking accuracy (both with respect to standard measuring error and for reasons of content: with greater significance of the larger deviations as a result of squaring). The learning schedule in that case consisted of 48 repetitions of single tracking task. Repetitions were blocked (3 trials in a block). The pause between each trial in one block lasted 5s. The rest periods between blocks were 1 minute long.

Measurements on the stabilometer as well as 2HAND and 3PTR procedures were repeated after 7 days to estimate the rate of learning. Simultaneously measurements of the following abilities were provided using procedures of the VST:

- simple reaction time (RT) - visual stimuli - and its deviation,
- time of simple movement (MT) and its deviation,
- speed of simple reaction and its deviation,
- speed of complex reaction and its deviation,
- speed of multiple reaction (visual and acoustic stimuli) and its deviation,
- maximal rate of hand movement (hand tapping),
- rhythm of movement in a guided phase – rhythm synchronization error (average difference tap-sound) (ms) and its standard deviation,
- rhythm of movement in an unguided phase – rhythm continuation error (average difference tap-tap-time) (ms) and its standard deviation,
- amount of detected signals and its time in signal detecting test (visual-space orientation),
- time (ms) and error of bimanual coordination test (movement combining),
- accuracy of tracking task – SDXY and SDZ (motor adjustment),
- integral of deviation's module in degrees (INTEGRAL) and number of changes of platform's movement direction (CHANGES) (balancing on the stabilometer).

All these procedures were proved as reliable and valid methods of coordinative abilities evaluation (Raczek et al. 2001). Obtained parameters from the VST were correlated with efficiency coefficients of motor learning of balancing and tracking tasks (due to variable B from regression of particular variables from stabilometer, 2HAND and 3PTR in regards to time/series). Backward stepwise regression was the main statistical method used in this work.

Results

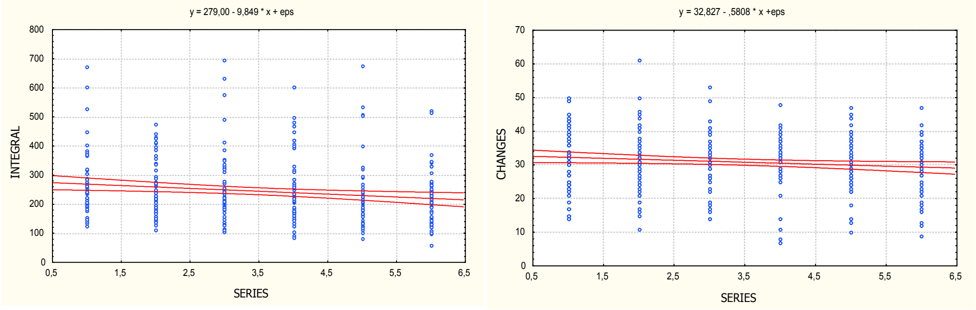
The analysis of acquired empirical data allowed to conclude that the progression of results in the task of balancing on a stabilometer was significantly better in both parameters (Fig.1). The analysis of variables using the linear regression in case of the basic parameter, which was the integral of deviation's module in degrees (INTEGRAL), showed that the improvement was statistically significant and total error decreased from 340,91±147,09 to 227,11±80,86 (F (1,328) = 7,467; p<0,001). In case of second variable improvement of number of changes of platform's movement direction (CHANGES), which parameter could be interpreted as an improvement of the personal stability, as well as created model of regression was statistically significant (average value decreased from 36,86±16,01 to 30,29±12,88 while F (1,328) = 4,133; p<0,05). It has to be emphasized that the measurement was repeated after 7 days and it was stated that performed successive repetitions increased the level of skill in case of both parameters.

The analysis of results with the use of linear regression in case of the variables obtained from the "Hand Coordination Test" (2HAND) also showed significant differences after the learning experiment (Fig.1). The test was performed faster at the end of the experiment and variable TIME decreased from 19,78±5,41 to 10,64±3,25 (F (1,108) = 58,835; p<0,001). The variable ERROR also was significantly improved – from 7,67±9,26 to 3,25±3,64 (F (1,108) = 4,692; p<0,05).

Blocked repetitions showed to be efficient also in case of learning the tracking task performed in 3-dimensional space (3PTR). The variable SDXY which characterized the error in horizontal and vertical planes, decreased from 15,45±3,73 to 12,06±2,83 (F (1,53)=16,004 p<, 001). At the same time, variable SDZ (describing the error in a size evaluation) decreased from 7,74±2,08 to 5,89±1,99 (F (1,53)=10,874 p<,005).

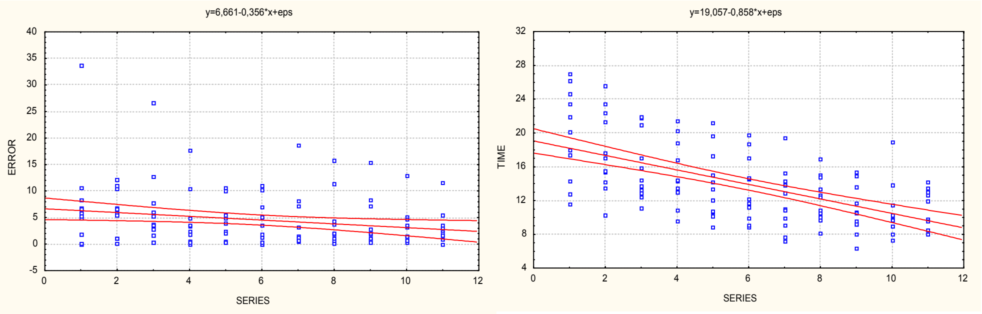
Measurements on a stabilometer as well as 2HAND and 3PTR tests were repeated after 7 days to establish the rate of learning. Results in these particular cases showed that performing successive repetitions increased the rate of learning of tracking skills in case of all analyzed parameters.

The correlation between learning coefficients of particular variables were calculated to answer one of the main questions of this experimental work. On the ground of those results, due to analysis of Pearson's coefficients, it could be stated that so-called learning coefficients do not correlate at all (none relationship was statistically significant).



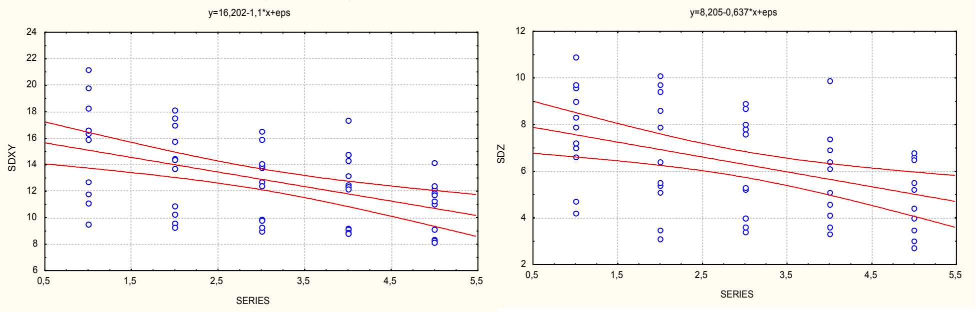
Integral of deviation's module in degrees (stabilometer)

Amount of changes of platform's movement direction (stabilometer)



% error time (2HAND)

Mean time taken for the total path (2HAND)



Mean deviation of tracking in XY planes (3PTR)

Mean deviation of tracking in Z plane (3PTR)

Fig. 1. The regression lines of results of motor learning of three skills

Concerning correlation coefficients matrix (Tab. 1.), it seems interesting that there were only several significant relationships observed. The significant relationship was established between efficiency of learning of the balancing task estimated due to regression of results of numbers of changes of platform's movement directions (B_CHANGE) and standard deviation of speed of complex reaction, coordination time and rhythm of movement in an unguided phase - average difference tap-tap-time and its standard deviation ($p<0,05$).

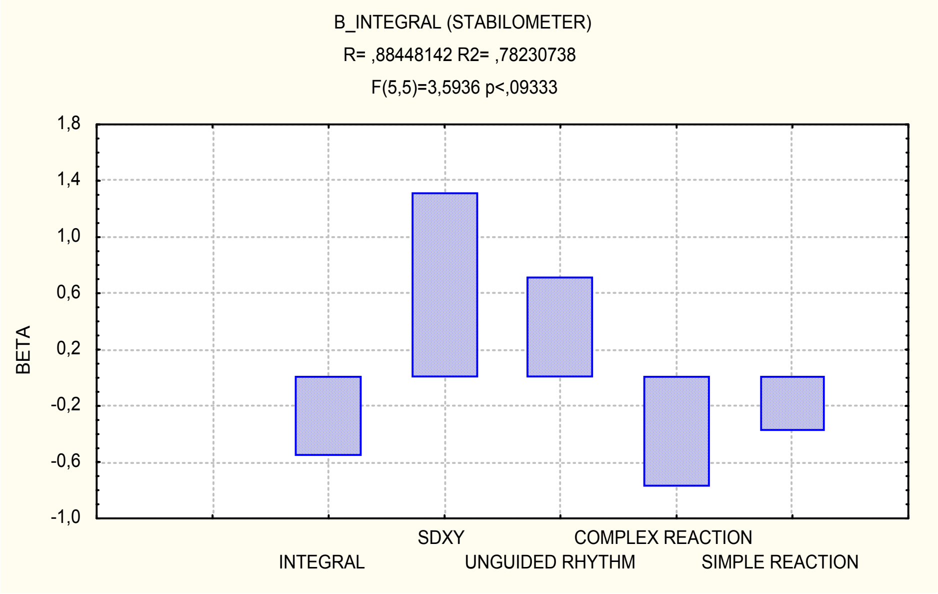
Surprising statement was obtained in case of learning of balancing task that the efficiency of learning did not depend on the initial level of balance.

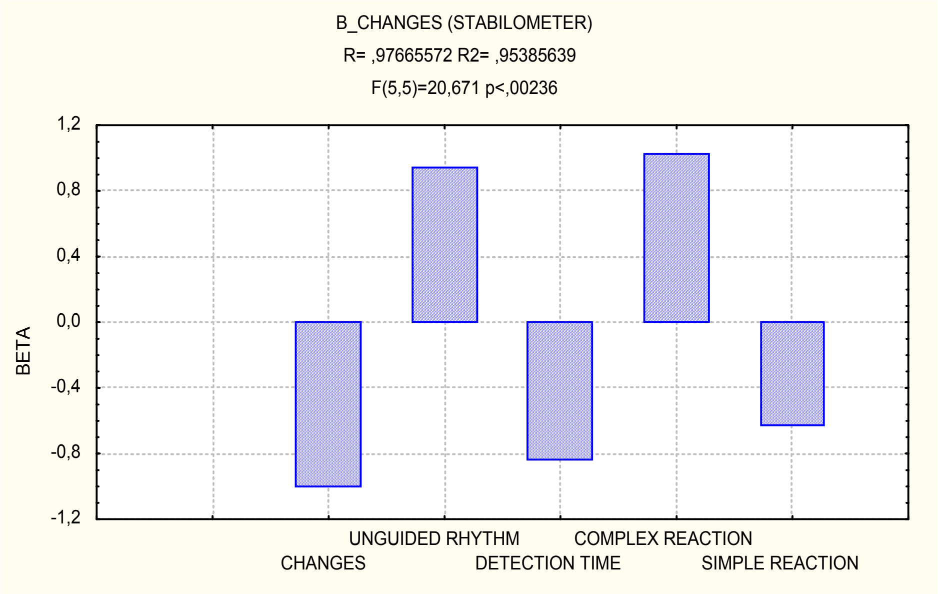
Table 1. Correlation coefficients among variables describing the efficiency of learning of balancing and tracking performance and the level of chosen temporal abilities

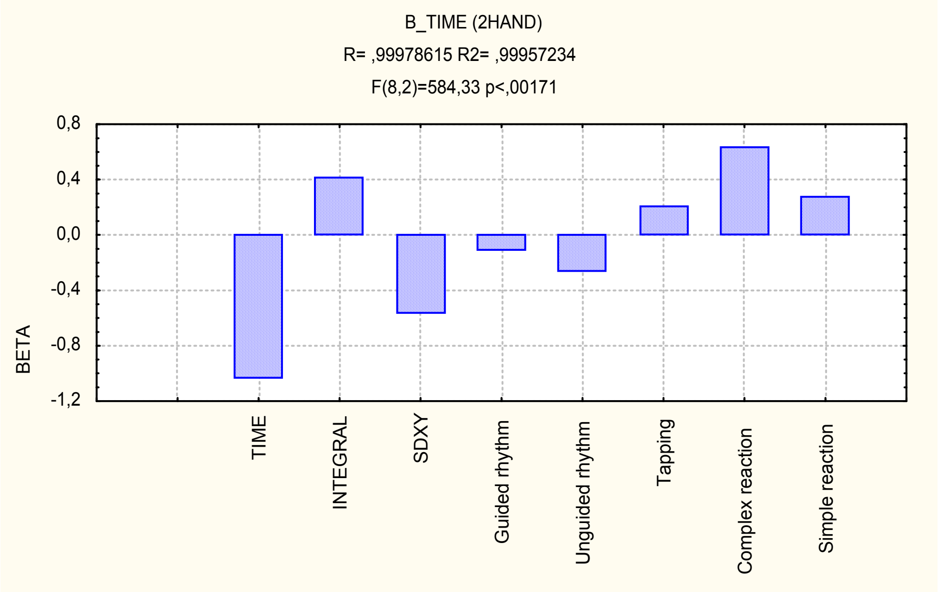
Variables	*B_INT (stabil.)*	*B_CHAN (stabil.)*	*B_TIME (2HAND)*	*B_ERROR (2HAND)*	*B_SDXY (3PTR)*	*B_SDZ (3PTR)*
Simple speed of reaction	0,03	0,18	-0,09	-0,43	-0,16	0,21
Simple reaction time	-0,20	0,23	0,36	-0,42	-0,02	-0,05
Simple movement time	0,10	0,03	-0,46	-0,28	-0,16	0,32
Simple speed of react.d.	0,35	0,10	-0,12	-0,03	-0,34	0,41
Simple react. time dev.	-0,05	-0,04	0,10	-0,19	0,06	0,30
Simple mov. time dev.	0,22	-0,49	0,03	-0,07	**-0,67**	0,29
Complex speed of react.	-0,12	-0,34	0,30	-0,41	0,22	**0,74**
Comp. speed of react. d.	0,02	**0,70**	-0,20	0,47	0,43	0,06
Multiple speed of react.	0,21	0,29	-0,07	**-0,66**	-0,52	0,02
Mult. speed of react. dev.	0,27	0,01	0,01	**-0,61**	-0,41	-0,04
Guided rhythm error	0,29	-0,27	0,04	-0,23	**-0,77**	-0,34
Guid. rhythm err. dev.	0,03	-0,23	-0,04	-0,46	**-0,75**	-0,04
Unguid. rhythm err.	0,18	**0,64**	-0,01	0,23	0,44	-0,19
Unguid. rhythm err. dev.	0,12	**0,67**	-0,08	0,08	0,44	-0,15
Maximal movement rate	0,13	0,26	0,05	0,08	-0,01	-0,41
Signal detection time	-0,13	-0,44	-0,06	0,31	0,20	-0,19
Amount of detec. signals	0,09	0,15	0,04	-0,51	-0,49	0,13
Coord. time (2HAND)	-0,07	**0,72**	**-0,84**	0,06	0,09	0,13
Coord. error (2HAND)	0,01	0,00	-0,20	**-0,80**	-0,19	0,09
SDXY (3PTR)	0,50	0,07	-0,06	-0,38	**-0,89**	-0,17
SDZ (3PTR)	0,42	0,33	-0,25	-0,31	**-0,64**	**-0,64**
INTEGRAL (stabilometer)	-0,17	0,29	0,07	0,32	-0,02	-0,45
CHANGE (stabilometer)	0,28	-0,31	0,13	0,12	0,00	-0,25

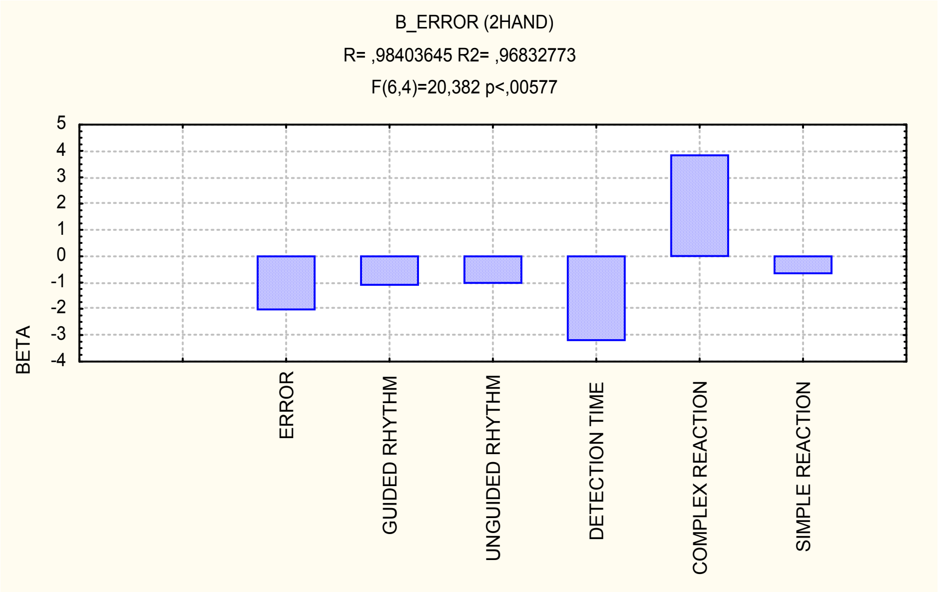
Statistically significant relationship are bold (p<0,05)

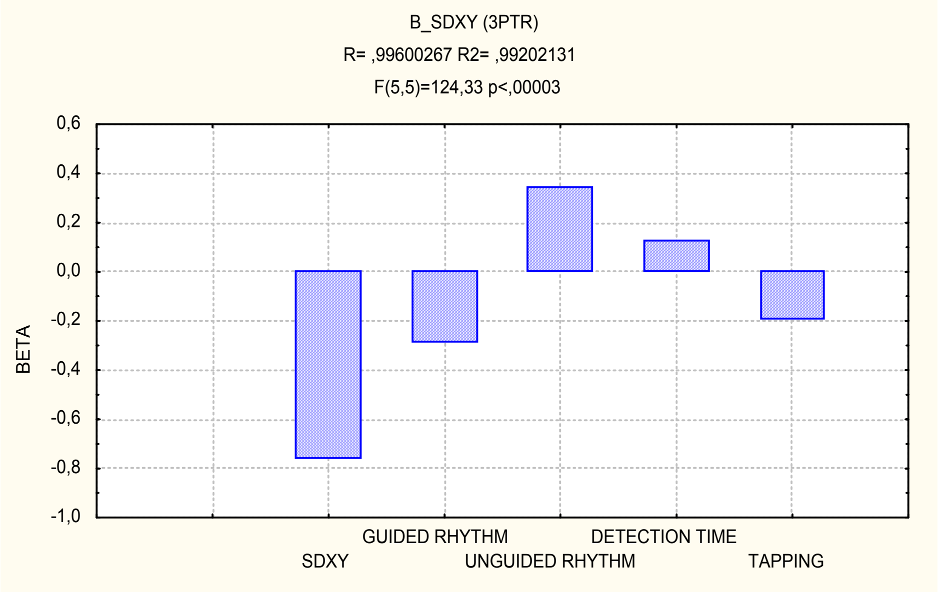
Efficiency of learning of the tracking task estimated due to regression of results of time of error (2HAND – B_ERROR) correlated statistically significant with speed of multiple reaction and its deviation. Both variables describing initial bimanual coordination was correlated with the efficiency of motor learning of that procedure.


B_INTEGRAL (STABILOMETER)
R= ,88448142 R2= ,78230738
F(5,5)=3,5936 p<,09333
BETA
1,8
1,4
1,0
0,6
0,2
-0,2
-0,6
-1,0
INTEGRAL
SDXY
UNGUIDED RHYTHM
COMPLEX REACTION
SIMPLE REACTION


B_CHANGES (STABILOMETER)
R= ,97665572 R2= ,95385639
F(5,5)=20,671 p<,00236
BETA
1,2
0,8
0,4
0,0
-0,4
-0,8
-1,2
CHANGES
UNGUIDED RHYTHM
DETECTION TIME
COMPLEX REACTION
SIMPLE REACTION


B_TIME (2HAND)
R= ,99978615 R2= ,99957234
F(8,2)=584,33 p<,00171
BETA
0,8
0,4
0,0
-0,4
-0,8
-1,2
TIME
INTEGRAL
SDXY
Guided rhythm
Unguided rhythm
Tapping
Complex reaction
Simple reaction


B_ERROR (2HAND)
R= ,98403645 R2= ,96832773
F(6,4)=20,382 p<,00577
BETA
5
4
3
2
1
0
-1
-2
-3
-4
ERROR
GUIDED RHYTHM
UNGUIDED RHYTHM
DETECTION TIME
COMPLEX REACTION
SIMPLE REACTION



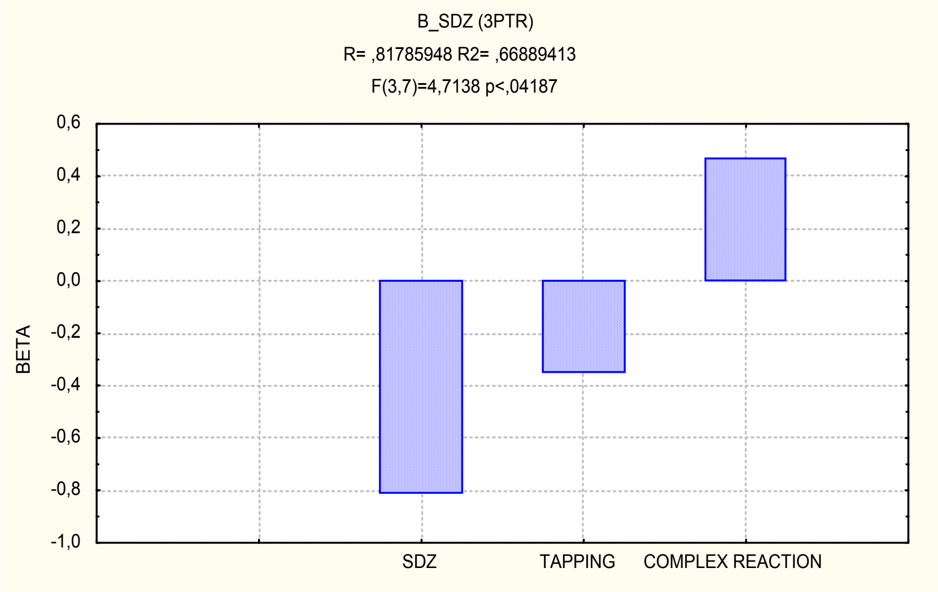


Fig.2. Influence of coordinative abilities on learning processes on the ground of results of backward stepwise regression

As far as significant relationship in efficiency of learning of 3-dimensional tracking (3PTR) estimated due to regression of changes of variable SDXY, it was possible to point out such an interplay with deviation of simple movement time and rhythm of movement in a guided phase - average difference tap-tap-time and its standard deviation. Second variable that determined the learning process of the 3PTR procedure – B_SDZ significantly correlates with speed of complex reaction ($p<0,05$). Also in case of that test both variables describing initial tracking ability were correlated with the efficiency of motor learning of that procedure.

Other correlations were not statistically significant.

Results of backward stepwise regression allowed pointing out variables, which significantly influenced the analyzed learning processes (Fig.2). On that ground it was possible to establish the independent factors, which determine the efficiency of learning of particular motor tasks. The most complicated situation was observed in case of balancing on the stabilometer. Efficiency of learning was not depended on the initial values of a variable describing an error of balancing (INTEGRAL) yet in others it was possible to create statistically significant models of regression. Besides the initial values of measured abilities some aspects of rhythm, orientation, motor adjustment and complex reaction seem to be the most significant predictors.

Discussion

The most dominant fact determined in this research was that the successive repetitions improved balancing skill and subjects became significantly better in two different tracking tasks at the end of experiment. The retention test (after 7 days as well) also showed significant improvement.

Concerning the researched relationship between learning coefficients of three different tasks it should be noticed that none of them were statistically significant. As far efficiency of learning of balancing on a movable platform and tracking tasks it is obvious that such an relation should not exist. It is interesting to note due to analysis of collected data that the effect of blocked repetitions of two other cases - different tracking tasks (2HAND and 3PTR) - do not correlate as well. First of all, it is proved that, when arms are moved simultaneously, a strong synchronization tendency becomes evident and this is interpreted by some to indicate that the limb musculature is constrained to act as a single functional unit or coordinative structure (Kelso et al., 1979). Additionally in that particular case, according to a similarity of so-called perceptual-motor workspace (the same control panel with joysticks and testing procedure), existence of relationship could be interpreted logically on the basis o known behavioral, kinesiological and neuro-anatomical evidence. Especially when notice that information was falling within a near, reachable space in both case. It seems that it was determined by egocentric co-ordinates selected by an attentional system devoted to the analysis of this portion of visual space during performing those tracking tasks. Results of regression proved that justification while measured aspects of orientation and complex reaction for visual stimuli were among most significant independent factors in analyzed models. At the same time it is worth to consider the problem of shifting visuo-motor attention in a virtual three-dimensional space, because what we know about spatial attention is mainly based on experiments that were conducted within a two-dimensional visual word (Posner 1980). Perhaps we should investigate this area to establish some principles on motor learning.

Concerning the researched relationship between chosen human elements and efficiency of the process of motor learning of a balancing and tracking tasks, we should be conscious of the fact, that effects of practice on particular movements are manifested in both spatial (e.g. directional error) and temporal (e.g. RT and MT) parameters of movement (Lee 2000). That particular research project was focused on temporal factors. It should be noticed that such an advance has a strong theoretical background. According to Bernstein's theory, the appropriate timing relations determine "motor problem" of learning of different tasks (Bernstein 1967) and obtained data look to confirm that principle. Different calculated learning coefficients correlate with different factors what means that it is impossible to establish the most important ability among investigated. If so, the researched relation is determined by task constraints, what is suggested in literature (Schmidt, Wrisberg 1999).

The chosen aspects of rhythm abilities were also identified as significant predictors what suggests that some aspects of timing underlie the performance of motor tasks. Simultaneously it should be stated that measured aspects of rhythm ability did not influence all performances. Robertson at al. (1999) presented a similar conclusion on the ground of their experiments on tapping and drawing tasks. They found that timing processes may not be shared across a wide variety of motor tasks. It is the evidence against a single timing process for motor control yet the problem of existing a general timing ability looks to be unsolved. At the same time it should be consider that the most of all calculated correlation coefficients were statistically insignificant, as well as most of analyzed variables did not influence efficiency of motor learning. These results did not clearly confirmed concepts presented in literature by Blume (1981), that all coordinative abilities influence motor learning processes. These relations are depended on performed motor task. Resuming, the findings reported in this work should be considered as a beginning of a line of experiments to fully test hypothesis of this research design and verify others.

Conclusions

Presented above results and the analysis of existing theoretical basis in the area of motor control and learning allow to formulate the following conclusions:

1. The motor learning processes are determined by coordinative abilities according to specificity of performed task.
2. The future development of research in the area of motor control and learning is possible only as a result of improved diagnostic tools to penetrate different human abilities, which underlie these phenomena.

REFERENCES

Beek, P.J., van Santvoord, A.A.M. 1992. Learning the cascade juggle: a dynamical system analysis. Journal of Motor Behaviour, 24, 85-94.

Bernstein, N.A. 1967. The coordination and regulation of movements. London, Pergamon Press.

Blume, D.D. 1981. Kennzeichung koordinativer Fähigkeiten und Möglichkeiten ihrer Herausbildung im Trainingsprozes. Wissenschaftliche Zeitzchrift der DHfK, 3, 17-41.

Brace, D.K. 1927. Measuring motor ability. New York: A.S. Barnes.

Fleishman, E.A. 1964. The structure and measurement of physical fitness. Englewood Cliffs, NJ: Prentice-Hall.

Fowler, C.A., Turvey, M.T. 1978. Skill acquisition: An event approach with special reference to searching for the optimum of a function of several variables. In: Stelmach, G.E. (Ed.): Information processing in motor control and learning. New York, Academic Press, 1-40.

Goodale, M.A., Milner, A.D. 1992. Separate visual pathways for perception and action. Trends in Neurosciences, 15, 20-25.

Gundlach, H., 1968: Systembeziehungen körperlicher Fähigkeiten und Fertigkeiten. Theor. und Prax. der Körperkultur, 2, 198-205.

Henry, F.M. 1961. Reaction time-movement time correlations. Perceptual and Motor Skills, 12, 63-66.

Kawato, M. 1999. Internal models for motor control and trajectory planning. Curr. Opinion Neurobiol., 9, 718-727.

Keele, S.W., Pokorny, R.A., Corcos, D.M., Ivry, R. 1985. Do perception and motor production share common timing mechanisms: A correlational analysis. Acta Psychologica, 60, 173-191.

Kelso, J.A.S., Southard, D., Goodman, D. 1979. On the nature of human interlimb coordination. Science, 203:1029-1031.

Latash, M.L. 1999. Mirror writing: learning, transfer, and implications for internal inverse models. Jour. Motor Behav., 31, 107-112.

Lee, D. 2000. Learning of spatial and temporal patterns in sequential hand movements. Cognitive Brain Research. 9, 35-39.

Newell, K.M. 1986. Constraints on the development of coordination. In: Wade, M.G., Whiting, H.T.A. (Eds.): Motor development in children: Aspects of coordination and control. The Hague: Nijhoff, 341-360.

Posner, M. 1980. Orienting of attention. Q. J. Exp. Psychol., 32, 3-25.

Raczek, J., Juras, G., Waśkiewicz, Z. 2001. The diagnosis of motor coordination. Jour. Hum. Kin., 6, 113-125.

Robertson, S.D., Zelaznik, H.K. Lantero, D.A. Gadacz, K.E., Spencer, R.M., Doffin, J.G., Schneidt, T. 1999. Correlations for timing consistency among tapping and drawing tasks: Evidence against a single timing process for motor control. Journal of Experimental Psychology: Human Perception and Performance, 25:5, 1316-30.

Schmidt, R.A., Wrisberg C.A. 1999. Motor learning and performance. A problem-based learning approach. Champaign.

Schmidt, R.C., Fitzpatrick, P. 1996. Dynamical perspective on motor learning. In: Zelaznik, H.N. (Ed.) Advances in motor learning and control. Champaign, 195-224.

Sternad, D., Katsumata, H. 2000. Dynamic stability in the acquisition and performance of a rhythmic skill: An example for a perception-action approach. Jour. Hum. Kin., 4, 57-73.