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Influence of increase of sensomotor task difficulty on neural system arousal and motoric performance

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Abstract
Introduction. **Requirements of current everyday life underline the importance of accurate and rapid response to the created situation. In addition to our ability to physically handle movement responses, it is very important to decide, which type of movement response is selected, and how a particular movement is programmed so that the movement response to the created situation could be adequate. If the difficulty of a sensomotor task is higher, the time needed to achieve the goal is extended – this fact was explored by Fitts already in 1954.** Aim of Study. **The objective of this study was to find out whether an increase in the difficulty of a performed movement task with certain demands on perception, thinking, attention, and memory can influence activation of the nervous system, and vice versa.** Material and Methods. **The test sample consisted of 84 persons (n = 84). The activation level of the nervous system was objectified by the measurement of skin conductivity with the device PowerLab, ML 116 GSR Amp from ADInstrument. The level of sensomotor performance was verified by the support drawing test.** Results. **The Friedman test result shows that there a significant difference exists in performance results in at least one measurement of the support drawing test. It is obvious from the table that the average values of time in all three measurements of the support drawing test are increasing. The effect size value of $\eta^2 = 1.16$ shows that, almost with a good degree of certainty, the result is not influenced by statistics tools.** Conclusions. **This research confirmed our expectations that the increased difficulty level of a sensomotor test of bimanual co-ordination has a significant impact on sensomotor performance, as well as on changes in activity of the autonomic nervous system. This study has a limited validity for the college student population at the age of 20-25 years.**

KEYWORDS: performed movement task, sensomotor test, nervous system.

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Introduction

The points in questions in reducing the natural physical activity have been solved worldwide by many research workers of various scientific disciplines. The physical inactivity of people causes a significant amount of problems that we are not even aware of in our daily lives [1, 28]. As demonstrated by a wide range of researches, lack of spontaneous physical activity affects a number of functions of the human organism, where a direct link is not sought, such as the quality of visual perception [24]. In our research, we would like to contribute to an increase in effectiveness of the sensomotor learning process, both in sports training of top-level athletes, and in recreational and spare-time sports, in the physical education of children and young people, and, last but not least, in learning to many types of work activities. We would also like to contribute to the description of some essential psychological factors, intervening in the sensomotor learning process.

If the difficulty of a sensomotor task is higher, the time needed to achieve the goal is extended – this fact was explored by Fitts already in 1954. He created a predictive model of human movement behaviour, known as Fitts' law. The objective of this study was to find out whether an increase in the difficulty of a performed movement task with certain demands on perception, thinking, attention, and memory can influence activation of the nervous system, and vice versa. Activation of the nervous system is influenced by a large number of cognitive processes [23]. Critchley talks about the integration of cognitive processes with autonomous control of body excitement, with a focus on a reciprocal impact of autonomous responses to decision making, error detection, memory, and emotions [9].

Requirements of current everyday life underline the importance of accurate and rapid response to the created situation. In addition to our ability to physically handle movement responses, it is very important to decide, which type of movement response is selected, and how a particular movement is programmed so that the movement response to the created situation could be adequate.

The voluntary course of movement is controlled by the somatic nervous system. This type of synergy is known as movement co-ordination, which is understood by Mechling and Effenberg as an interaction of the CNS and skeletal muscles during the movement [20]. We can distinguish between intramuscular (neuromuscular) and intermuscular co-ordination (co-ordination of individual muscles and muscle groups). The above-mentioned authors define co-ordination abilities as complex prerequisites to perform movement activities, enabling learning, performing movement skills, and their manifestations. The movement co-ordination as a process of sorting out redundant movements from the overall motor performance, and finding an optimal, time-efficient algorithm for a high degree of movement control [4]. The activities requiring co-ordination of both hands are called bimanual activities [8]. These involve fundamental, every-day self-help skills (shoelace tying, use of cutlery, and the like), or wholly specialised activities – various work activities, playing musical instruments, and sports skills. Movements, which are the result of co-operation of both hands, require very precise timing. The factors affecting the level of bimanual co-ordination. Among other factors, we can mention, for example, previous experience with bimanual activity, age, and gender [2, 3, 26]. The efficacy of bimanual co-ordination depends on integrity of the corpus callosum, which helps in co-ordination of movement activity from opposite sides of the body [21]. Involvement of more than one limb in performing functional and goal-targeted actions, is probably one of the most important, specifically human abilities [22]. Bimanual movements can be either symmetrical, or asymmetrical. Processing and preparation of a movement response to an asymmetric bimanual task takes longer than processing and preparation to a symmetric task [5]. Neurophysiological studies relating to bimanual co-ordination are primarily focused on the two following cortical areas:

1) Supplementary motor cortical area, where stimuli for movement are created, and which is involved in learning complex movements [13]. This area also participates in the initiation and programming of individual segments of complete movements [7], body postural control [10].

2) Primary motor cortical area, where stimuli leading to movements of opposite sides of the body are created [12], muscle activity [25], speed and acceleration of movement [11], and is also involved in bimanual movements [10]. The involvement of the subcortical structures in bimanual co-ordination is also very important, as the supplementary motor cortical area is interconnected just with a wide range of these structures [19]. The activation level, sometimes referred to as nervous system activity, is another theoretical starting point of our problem. It is given by the level of brain activation. We regard it as one of the characteristics of the current mental condition [17]. The change in activation is associated with the change in activity of the autonomous nervous system (ANS). Irmiš defines the autonomous nervous system as a "set of nerve cells and fibres conducting impulses to other tissues than the striped muscle, which is subject to voluntary control" [16]. The term "autonomous" means relative uncontrollability by the will in comparison with the somatomotor system. Most of the time, we are not aware of the control of this system. Similary as with the somatic system, most of the ANS functions are organised on the basis of a reflex arc. The ANS contains efferent (centrifugal) and afferent components [16, 17]. Both functionally and structurally, the ANS is connected with the somatic and humoral system.

One of the possibilities how to objectify and quantify the nervous system activation is to measure electrical effects on the skin, which are collectively referred to as electrodermal activity (EDA). EDA is an electrical effect, which is manifested in the skin resistance change and skin conductivity (inverted value of the skin resistance). Due to subjective activity of the autonomous nervous system, especially its sympathetic nervous system, skin conductivity is inter-individually very different [16, 18]. EDA is based on a change in sweat gland permeability in the skin and subcutaneous tissues, and is one of the few parameters which can quickly respond to changes in the readiness of the organism to responses. The electrodermal activity is a result of stimulation of ecrine glands in the skin, resulting in a change in conductivity of electrical current. If a person relaxes, the skin conductivity decreases. If the mental stress is higher, the skin conductivity increases [6]. The sympathetic activity, which causes the electrodermal reaction, is connected with emotional and cognitive states. EDA is used as a sensitive index of physical excitement, associated with the course of emotions and attention. On the skin, two basic bioelectric effects can be observed. Firstly, this is a long-term tonic level of skin conductivity, which can remain for several hours or days. Secondly, this is a phasic, so-called electrodermal reaction, which very sensitively notices any deviation in activation of the nervous system. After the disappearance of the stimulus that caused the reaction, EDA returns to its original level [6].

It is assumed that if the difficulty of a sensomotor task is increased, the length for which a certain task is performed by probands, will be extended. By increasing difficulty of the task, the activation of the nervous system is changed.

Material and Methods

The test sample consisted of 84 persons (n = 84). All probands were students of the Faculty of Education of the University of West Bohemia, Pilsen, Czech Republic. Of these, 42 females and 42 males were at the average age of 21.4 years (± 2.78 years). The sample was selected on the basis of their willingness and availability [15].

Measurement of electrodermal activity

To determine average values and average sizes of changes in electrodermal activity (skin conductivity), we used the ML 116 GSR Amp device from ADInstrument. This device utilises PowerLab Chart software, which records a time series of skin conductivity data between two electrodes located on distal phalanges of the middle finger and ring finger of the non-dominant hand, so that the proband could easily control the test device by his/her thumb and forefinger of both hands. Bipolar finger electrodes (ml 116F), ensuring sensing of skin conductivity, are fixed with Velcro tapes to the distal phalanges of the non-dominant hand. This device utilises a 75 Hz oscillator with an almost rectangular wave, low voltage (22 mV) between the electrodes, and low impedance. The device is equipped with the safety galvanic isolation and IEC601-1 BF standard certification for devices connected to the human body. Skin conductivity is given in units of electrical conductivity, microsiemens (μS).

The EDA measurement was initiated by connecting the electrodes and calibrating the device to a resting level of a proband. The measurement was performed for the entire duration of testing, and at all three difficulty levels of a sensomotor task. The device recorded a time series of skin conductivity every 0.25 s. From this time series, Lab Chart software determined the average value of skin conductivity. From the time series, we calculated the average size of EDA change, specifically by subtracting the maximum and minimum EDA values, we determined a range of variation in each five-second interval. From the values obtained in this manner, we calculated the arithmetic average (Formula 1).

$$PVZ = \frac{\sum_1^n R}{n}\,; R = (x_{max} - x_{min})$$

at particular time (Formula 1)

Sensomotor test of bimanual co-ordination – support drawing

To determine the level of bimanual co-ordination, we chose the support drawing test, which was also used in the past. This is a physically non-demanding test, which is suitable for the purposes of this research mainly due to the elimination of sweating, and on the ground of increase in movement intensity.

During the support drawing test, the tested person, by using two control loops, controls the tip of the recording device in a two-dimensional space, circular ring. With one hand, the person moves the tip vertically along the y-axis, and horizontally along the x-axis. The tested person's task is to ideally describe a circle into the prepared circular ring so that the tip of the device will not go out of the circular ring. Such a case is considered a mistake. For the purposes of our research, we chose three levels of test difficulty, which are given by the gradual reduction of the circular ring. In the first measurement, the circular ring width was 15 mm, in the second measurement, the width was 12 mm, and in the third measurement, it was 9 mm. Accuracy and speed of performance are the major criteria. In a preliminary research, this test was standardised. The internal consistency of the test was assessed by the Cronbach's alpha coefficient ($\alpha = 0.89$, $p < 0.01$). The test objectivity ($R_o = 0.92$, $p < 0.01$) was verified by the time measurement method by two examiners.

The testing was carried out in the laboratory of exercise diagnostics, Faculty of Education of the University of West Bohemia in Pilsen. For the entire duration of testing, we tried to ensure standard conditions for all persons being tested. The room was always properly ventilated, quiet, with adequate light and temperature. During testing, we used a computer equipped with software, which recorded the time series of skin conduction, and a stopwatch, which measured the time of individual attempts. After coming to the laboratory, the proband sat down at a measuring desk, and electrodes for the measurement of EDA were connected to his/her hand. Then, the proband was acquainted with the support drawing test and the rules of proper handling with the hand with the installed electrodes. In this manner, we tried to eliminate as much as possible the possibility of pressure exerted on the electrodes. After two minutes following the attachment of electrodes, the examiner calibrated the EDA measuring device, and the test was initiated. At all levels of difficulty, the time series of skin conductivity values, time during which the proband drew the whole circular ring, and the number of errors were recorded.

Statistical methods used

For the purposes of comparison of individual variables, the descriptive statistical characteristics, arithmetic average, and standard deviation were used. To assess changes in the variables ascertained in individual measurements with the increased difficulty in the support drawing test, the non-parametric Friedman test for multiple dependent files was used. The significance level was set at: $\alpha < 0.01$. To assess the difference between individuals who made errors, and those who did not make error, the non-parametric Mann–Whitney test for two independent files was used. The significance level was set at: $\alpha < 0.1$. To increase the conclusive evidence of the results of statistical processing, in case of the Friedman test, we used the calculation of statistical significance η^2 according to Formula 2, and for the Mann–Whitney U test, we used the Cohen *d* [27], according to Formula 3.

$$\eta^2 = \frac{x^2}{N - df} \quad \text{(Formula 2)}$$

$$d = \frac{M1 - M2}{SD} \quad \text{(Formula 3)}$$

For the calculation of the Friedman test and Mann–Whitney U test, the STATISTICA 6.0 program was used. List of abbreviations of variables:

- SK1 – performance in the first measurement of the support drawing test; circular ring width of 15 mm, assessed as execution speed (second);
- SK2 – performance in the second measurement of the support drawing test; circular ring width of 12 mm, assessed as execution speed (second);
- SK3 – performance in the third measurement of the support drawing test; circular ring width of 9 mm, assessed as execution speed (second);
- PR_EDA1-3 – average EDA value during the first – third measurement of the support drawing test (microsiemens);
- PVZ_ EDA1-3 – average change in the EDA value during the first – third measurement of the support drawing test (microsiemens).

Results

In the interpretation of differences between SK1-3, PR_ EDA1-3, and PVZ_EDA 1-3 dependent variables, we used tables containing information about the Friedman test value (χ^2), statistical significance (p), and the average sum of order, sum of order, average value, and standard deviation.

First, we assessed the differences in performance of the increasing level of difficulty of the support drawing test (Table 1).

Table 1. Results of Friedman test at each difficulty level of the support drawing test

χ^2 (N = 84, df = 2) = 95.40181, p < 0.00000*

	Average rank	Sum of ranks	Mean	Std. Dev.
SK1	1.39	116.5	68.83	17.48
SK2	1.78	149.5	71.25	14.06
SK3	2.83	23	86.40	19.59

* $p \leq \alpha \leq 0.01$

The Friedman test result shows that there a significant difference exists in performance results in at least one measurement of the support drawing test. It is obvious from the table that the average values of time in all three measurements of the support drawing test are increasing. The effect size value of $\eta^2 = 1.16$ shows that, almost with a good degree of certainty, the result is not influenced by statistics tools.

Also in this case (Table 2), we reported a statistically significant increase in the mean EDA values for all three measurements. The effect size value of $\eta^2 = 0.23$ still indicates a very high substantive significance.

Table 2. Results of Friedman test at variable mean EDA value

χ^2 (N = 84, df = 2) = 18.88095, p < 0.00008*

	Average rank	Sum of ranks	Mean	Std. Dev.
PR_EDA_1	1.75	147	2.45	3.76
PR_EDA_2	1.87	157	3.03	5.64
PR_EDA_3	2.38	200	4.26	6.60

* $p \leq \alpha \leq 0.01$

With the increasing difficulty level of the support drawing test, the value of the average magnitude of EDA change shows significantly lower values (Table 3). The value of $\eta^2 = 0.63$ means again a very high effect of increasing the test level difficulty on reducing the values of the variable average magnitude of EDA change.

Table 3. Results of Friedman test at the variable average size of the EDA change

χ^2 (N = 84, df = 2) = 51.52381, p < 0.00000*

	Average rank	Sum of ranks	Mean	Std. Dev.
PVZ_EDA_1	2.5	210	0.92	0.68
PVZ_EDA_2	2.09	176	0.84	0.71
PVZ_EDA_3	1.40	118	0.64	0.39

* $p \leq \alpha \leq 0.01$

In the next step, we desired to find if there exists a difference in the speed of test performance, in the average EDA value, and in the average magnitude of EDA change between the individuals who made errors, and those who did not make errors. The total number of individuals who made errors in the first measurement of the mirror drawing test was 7 probands, 12 probands in the second measurement, and 36 probands in the third measurement.

Significant differences between the individuals who made errors, and those who did not make errors were ascertained in the case of SK2, PVZ_EDA2, and PVZ_EDA3 variables. The substantive significance confirmed the mean effect in the case of performance in the second measurement of the support drawing test (SK2), $d_{SK2} = 0.58$. The mean effect of influence of erring was also ascertained at the average magnitude of change in EDA variable (PVZ_EDA3) in the third measurement of the support drawing test, $d_{PVZ\_EDA3} = 0.51$. The substantive significance did not confirm the erring effect in case of the average magnitude of EDA change variable in the second measurement of the support drawing test (PVZ_EDA2).

Discussion

Due to the fact that both females and males participated in our research, we had to be necessarily interested in seeing any differences between these genders. In this respect, we found very interesting facts outlined in the discussion section, even though these facts originally were not the goal of our research. In speed of test performance, statistically and objectively significant differences were found between males and females in speed of test performance, when males performed the test faster. As regards the number of errors, performance of males and females were comparable, with the exception of the second measurement (SK2), where only 2 males made 1 error, while 9 females made 1 error, and 1 female made 2 errors. In the first and third measurement of the supportive drawing test, females made fewer errors than males.

Information about the effects of gender on movement performance is known from various clinical researches, but it has not been satisfactorily explained yet [26]. The gender differences in human cognitive and motor skills, which may be partially caused by organisational or activation effects of sex hormones in the brain. Oestrogen is related to various stages of the menstrual cycle, and the high level of gonadal steroids present in the luteal phase of the cycle may explain the variable performance in females [14]. Gender differences in the corpus callosum morphology are also documented [14], and the effectiveness of bimanual co-ordination depends on its integrity [21].

It is also necessary to note that in connection with the ascertained differences between males and females, there exists a difference between the individuals who make errors, and who do not make errors. A statistically and objectively significant difference was found between the individuals who made errors, and those who did not make errors, in speed of performing the second measurement of the supportive drawing test (SK2). Due to the fact that the females made errors more frequently than males in this measurement, and the females were significantly slower in all supportive drawing tests, it is likely that these findings are affected by the inter-gender differences. It is not entirely clear, however, why the males made fewer errors in the second measurement of the test.

Regarding the changes in EDA, the statistically and objectively significant differences were ascertained in average skin conductivity values, and in values of average magnitude of changes in skin conductivity, recorded in individual difficulty levels of the supportive drawing test. The assumption that activity of the autonomic nervous system, and also certain cognitive functions will be increased with the increasing level of difficulty of a sensomotor task, is supported by the ascertained differences in the average of electrodermal activity variable (PR_EDA1-3). The values of this variable and dispersion of these values increase evenly. The course of the measured values in individual measurements of the supportive drawing test is decreasing in the average magnitude of EDA change variable (PVZ_EDA1-3). This virtually means that the course of the curve created by the time series of skin conductivity data, depending on the difficulty level of task, shows smaller fluctuations. This phenomenon can be attributed to increased concentration of the subject.

With regard to statistically and materially significant differences in EDA values ascertained between the group of probands who made errors, and those who did not make errors, we can also see a trend of smoothing the curve of skin conductivity values during the third measurement of the supportive drawing test. In other words, the value of the average magnitude of EDA change variable decreases in the third measurement of the test (PVZ_EDA3).

Conclusions

This research confirmed our expectations that the increased difficulty level of a sensomotor test of bimanual co-ordination has a significant impact on sensomotor performance, as well as on changes in activity of the autonomic nervous system. The fact that increasing the difficultly significantly extends the test execution time and error rate, confirms our assumptions that the difficulty level has been correctly chosen from the viewpoint of performance comparison in our individual measurements, and this was even manifested in the changes of the values of both EDA variables. By increasing the difficulty of the sensomotor test, the average EDA value is increased, and, on the contrary, the value of the average magnitude of EDA variable change is decreased. This fact is attributed to the increased activation of the nervous system, increased concentration and attention during a particular sensomotor performance. The decrease in EDA scattering during testing refers to certain increase in concentration on a sensomotor task. As it was interpreted in the discussion section, significant differences in performance, or in the speed of test execution, were found between the males and the females. The difference between them has not been identified in the variables relating to electrodermal activity.

No differences in speed of test execution, or in average EDA values, were observed between the individuals who made errors, and those who did not make errors. A statistically and materially significant difference was ascertained in the case of the third measurement of the average magnitude of EDA change variable. It should be noted that the second degree of difficulty of the sensomotor test was not sufficient to clearly demonstrate the influence of difficulty level on success in this test, and in on-going changes in activity of the autonomic nervous system.

From the results of our research, we can conclude the following facts: the increasing difficulty level of the sensomotor test is manifested in the length of its execution, activation of the nervous system is increased, and changes in activation of the nervous system are decreased. We assume that the increased difficulty level of the sensomotor test led to more precise bimanual co-ordination by adjusting the motion program according to the immediate feedback. This fact increases the demands on sensory perception (visual and proprioreceptive) of sensomotor performance. If we want to increase the difficulty of exercising in practice, it is advisable to draw attention to the higher difficulty of the movement task and also to increase the activation of the nervous system. The validity of this study is limited to students at the age of 20-25 years.

We intend to continue in our research and hope that can contribute to answering some questions regarding the effectiveness of sensomotor learning of individuals.

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