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ФИЗИОЛОГИЧЕСКАЯ ЦЕНА ЦЕЛЕНАПРАВЛЕННОЙ ДЕЯТЕЛЬНОСТИ У ЛЮДЕЙ С РАЗНОЙ РЕЗУЛЬТАТИВНОСТЬЮ В ДИНАМИКЕ ЭНДОХИРУРГИЧЕСКОГО ТРЕНИНГА

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Цель. Изучение физиологической цены результата целенаправленной деятельности человека на модели эндохирургического тренинга. ***Материалы и методы.*** В работе приняли участие 87 мужчин в возрасте 18-24 лет. Испытуемым предлагалось выполнить ряд упражнений по системе «Базовый эндохирургический симуляционный тренинг и аттестация» (БЭСТА) с использованием коробочного тренажера T5 Large RM на протяжении 10 ежедневных тренировок по 30 мин каждая. Фиксировали число допущенных ошибок и время выполнения манипуляций. Во время тренировок регистрировали электромиограмму на аппарате BIOPAC MP 36. Регистрацию и обработку электрокардиограммы (ЭКГ) проводили до и после тренировок с использованием комплекса «Варикард 2.51». При оценке данных ЭКГ использовали среднюю разницу характеристик спектрального анализа вариабельности сердечного ритма до и после тренинга. ***Результаты.*** Показано, что высокорезультативные индивиды характеризуются меньшими энергозатратами на совершение двигательной работы в процессе целенаправленной деятельности. Независимо от результативности, целенаправленное поведение в условиях психоэмоционального стресса сопровождается истощением функциональных резервов организма. Низкорезультативные испытуемые демонстрируют более выраженное ослабление парасимпатических (в начале наблюдений) и симпатических (в конце исследования) влияний на функциональную активность сердца. ***Заключение.*** Выявлены особенности физиологического обеспечения целенаправленного поведения у людей с разной результативностью деятельности на модели эндохирургического тренинга. Достижение лучшего результата в динамике целенаправленной деятельности на указанной модели обеспечивается большей физиологической ценой.

Ключевые слова: *целенаправленная деятельность; практическая эндохирургическая подготовка; вариабельность сердечного ритма; электромиография.*

PHYSIOLOGICAL ‘COST’ OF ACTIVITY OF INDIVIDUALS WITH DIFFERENT EFFECTIVENESS IN DYNAMICS OF ENDOSURGICAL TRAINING

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Aim. The work was designed to study the physiological ‘cost’ of purposeful behavior on the model of endosurgical training. ***Materials and Methods.*** The research was implemented on 87

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men of 18-24 years of age. The volunteers per formed a number of exercises 30 minutes each according to the Basic Endosurgical Simulation Training and Attestation System (BESTA system) on a T5 Large RM box-trainer within 10 consecutive days. The total time and the number of mistakes were recorded. During the training sessions an electromyogram was recorded on a BIOPAC MP 36 device. ECG was recorded and processed using a Varicard 2.51 device before and after the training sessions. ECG was analyzed by evaluation of the average differences of spectral analysis of heart rate variability before and after training. ***Results.*** It was shown that high-performance individuals were characterized by less energy spent on motor work in purposeful activity. Irrespective of the effectiveness of training, the purposeful behavior in conditions of psychoemotional stress was characterized by depletion of functional reserves of an organism. Low-performance subjects demonstrated a more evident weakening of parasympathetic (start of observations) and of sympathetic influences (end of observations) on the functional activity of the heart. ***Conclusion.*** Specific features of physiological 'cost' of purposeful behavior in individuals with different effectiveness of the activity were revealed on the model of endosurgical training. Better results in the dynamics of purposeful activity were achieved on this model at a higher physiological 'cost'.

Keywords: *purposeful behavior; practical endosurgical training; heart rate variability; electromyography.*

According to modern scientific views, the basis of systemic organization of purposeful behavior is motivation arising from the dominating need [1,2]. It is absolutely evident that effectiveness of purposeful activity (PA) may vary within a wide range depending on different factors. The effectiveness of the activity is understood as a physiological 'cost' of a unit of the activity result [3,4].

Despite a considerable contribution of researchers to understanding of regulation and physiological provision of PA, the results achieved in this field, are controversial in many aspects. According to some authors, purposeful activity is accompanied by activation of stress-realizing systems of an organism, to a larger extent in high-performance individuals [5]. Other authors believe that high results of PA are achieved by individuals with predominating influence of parasympathetic division of the nervous system on the functional activity of the heart [6]. It should be emphasized that the overwhelming majority of observations were conducted on experimental models with a single record of physiological parameters and parameters of the achieved result of PA. There exists not that much information about variation of the mentioned characteristics in the dynamics of behavior and in achieving the plateau of the result.

Nowadays, researchers pay special attention to assessment of physiological 'cost' of purposeful behavior in psychoemotional stress [7,8]. It seems important to study peculiarities of physiological provision of behavior of individuals with different success of PA in conditions of stress using complicated experimental models.

Aim. To study the physiological 'cost' of the result of purposeful activity on the model of endosurgical training. To determine changes in the parameters of heart rate variability and in electromyogram of individuals with different effectiveness of the purposeful activity in the dynamics of observations in the mentioned experimental conditions.

Materials and Methods

Observations were conducted on 87 men aged 18-24 years studying in A.I. Evdokimov Moscow State University of Medicine and Dentistry. The study was conducted in compliance with the principles of Declaration of Helsinki. The main criterion for inclusion into the study was absence of experience of working with endosurgical instruments and also absence of diseases of musculo-skeletal apparatus and of the nervous system, and normal acuity of vision. On the stage of assessment of the functional

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condition, individuals with deviations from the reference range of age-related norms were excluded.

Before the 1st day of training the participants were demonstrated the basic techniques of working with endosurgical instruments. Every day the participants were performing on an endosimulator 3 basic exercises selected from modern simulation endosurgical training programs: Objective Structured Clinical Examination, (OSCE) [9], Global Operative Assessment of Laparoscopic Skills (GOALS) [10], Basic Endosurgical Simulation Training and Attestation (BESTA) [11,12].

All participants passed 10 trainings on box simulator T5 Large RM (3-DMed, USA). The training day included 3 tasks, with 5 minutes given for each. Task №1 consisted in transportation of 4 foam balls (d=3 mm) from the initial position to the tops of posters using an endoclamp (h=20 mm, d=2 mm). The task was performed by the right and left hand in turn.

Task №2 consisted in bimanual translocation of 6 hollow foam cylinders (h=20 mm, d=6 mm, d_1=4 mm), placed on plastic posters (h=20 mm, d=2 mm), to posters of the same dimensions positioned at 40-80 mm from the initial ones. The participants raised a cylinder with an endoclamp in the dominating hand, passed it to the endoclamp in the other hand without touching the surface of the working area, and placed it on a free poster.

Task №3 consisted in bimanual cutting of a circle with 10 cm circumference out of paper tissue. Endoscissors were in the dominating hand, and an endoclamp – in the other hand.

During 5 minutes of performing the exercise the number of mistakes and uncompleted elements were recorded. In the 1st and 2nd tasks a mistake was considered to be a loss of an object out of the endoclamp or its contact with the surface. On expiry of the time given for the task, all non-transported objects were considered mistakes. In the 3d task the quantitative parameter of a mistake was the sum of the lengths of incorrectly cut out circle with crossing of its contour (cm) and the length of a circle that remained non-cut out after expiry of the preset time interval (cm). Individual achievements of each participant were recorded in a check-list. In the subsequent analysis the overall time spent on completion of all tasks was calculated, and also the overall number of mistakes per each training day. The participants were arranged into groups on the basis of the obtained results.

During each training session an electromyogram (EMG) was recorded using a surface method on BIOPACMP 36 device (BIOPAC® Systems, Inc., USA) in the 5-500 Hz range. Electrodes were fixed on the inner surface of both forearms. Assessment was based on the area of the curve wave (mW^2) calculated using BIOPAC Student Lab PRO program.

Every day before the training a participant stayed in the condition of operative rest within 1 h. 5 Min before and after each training session, ECG was taken in a sitting position (the time interval between taking ECG and start/end of the training did not exceed 30s). Record and processing of ECG with subsequent calculation of heart rate variability was performed on Varicard 2.51 complex (OOO IVSTCRAMENA, Russia). HRV was analyzed according to recommendations of International Standard [13-15]. In assessment of ECG, HRV parameters were used: total spectral power – TP (ms^2), spectral power in high-frequency range – HF (ms^2), spectral power in low-frequency range– LF (ms^2). Besides, the mean difference between characteristics of spectral analysis of HRV before and after training was also determined: between total spectral power – ΔTP (ms^2), spectral power in the high-frequency range ΔHF (ms^2), spectral power in the low-frequency range (ms^2).

On the basis of the parameters of effectiveness of the training activity, participants were divided to the stated below groups.

Classification by speed of fulfillment of the tasks:

- I-B group – subjects with high speed of fulfillment of the tasks (n=22; 25.29%), I sample quartile, median of the 1st day of training – 515 s (interquartile range, IQR, 480-525 s), me-

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dian of the 10th day – 240 s (IQR 232-251 s);

- II-B group – a group of average values (‘background’; n=43; 49.42%), II-III sample quartile, median of the 1st day of training 624 s (IQR 584-652 sec,), median of the 10th day of training – 625 s (IQR 308-345 s);
- III-B group – subjects with low speed of fulfillments of the tasks (n=22; 25.29%), IV sample quartile, median of the 1st day of training – 777 s (IQR 741-802 sec), median of the 10th day of training – 405 s (IQR 391-426 s).

Classification by the quantity of mistakes:

- I-O group – subjects with a small number of mistakes (n=22; 25.29%), I sample quartile, median of the 1st day of training – 6.1 (IQR 3.3-7.2), median of the 10th day of training – 1.3 (IQR 1-1.5);
- II-O group – a group of medium values (‘background’; n=43; 49.42%), II-III sample quartile, median of the 1st day of training – 11.6 (IQR 9.6-13.4), median of the 10th day of training – 3.55 (IQR 2.7-4.2);
- III-O group – subjects with a large number of mistakes (n=22; 25.29%), IV sample quartile, median of the 1st day of training – 20.9 (IQR 17.1-24.4), median of the 10th day of training – 6.3 (IQR 5.75-7.15).

In line with the general aim of the study, further analysis of physiological parameters in the dynamics of endosurgical training was conducted on the participants with the extreme parameters of effectiveness of PA included into I and IV quartiles of samples.

Statistical processing of the data was performed using Statistica 10.0 program (Stat Soft Inc., USA). Assessment of the data for normalcy of distribution was performed using Kolmogorov-Smirnov test and Shapiro-Wilk test. In assessment of all the data, methods of non-parametric statistics were used. Statistical significance of differences was evaluated by Mann-Whitney and Wilcoxon tests. Correlation analysis was carried out using Spearman’s correlation coefficient. Statistically significant were considered parameters at $p<0.05$.

Results and Discussion

The total area of the EMG curve recorded both in the initial condition and at the end of observations was found to be smaller in I-B group than in III-B group (Table 1). The difference of the parameter between the groups on the 1st day of training was 41.51 mW^2 (79.91%; $p<0.0001$), and on the 10th day it decreased down to 23.22 mW^2 (83.91%; $p<0.0001$). Similar results were obtained in groups formed according to the number of mistakes. The total area of the curve wave for the mentioned days of training was smaller in I-O group than in III-O group (Table 1). The intergroup difference of this parameter on the 1st day was 39.34 mW^2 (69.13%; $p<0.02$), on the 10th day it decreased down to 7.94 mW^2 (24.5%; $p>0.05$).

Table 1

Area of Wave of EMG Curve in Different Groups of Participants

Day of Observation	Group I-B (mW^2)	Group II-B (mW^2)	Group III-B (mW^2)	Group I-O (mW^2)	Group II-O (mW^2)	Group III-O (mW^2)
1st	51.94 (42.05-62.34)$^{*,\#}$	62.73 (50.3-87.91)*	93.45 (68.45-140.21)	56.91 (42.36-72.27)$^{+}$	61.21 (51.62-88.2)$^{+}$	96.25 (65.78-136.97)
10th	27.67 (23.46-34.06)$^{*,\#}$	35.84 (31.71-48.67)*	50.89 (42.63-60.15)	32.41 (28.34-40.65)$^{+}$	35.37 (27.84-48.67)$^{+}$	40.35 (32.21-60.14)

Note: *$p<0.05$ in comparison with individuals of group III-B on the respective day of training; #$p<0.05$ in comparison with individuals of group II-B on the respective day of training; +$p<0.05$ in comparison with individuals of group III-O on the respective day of training: median and interquartile interval 25 and 75%.

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In comparison of HRV parameters in people with different effectiveness of the training activity all groups showed reduction of the total power of HRV spectrum (Table 2).

Table 2

Parameters of HRV Dynamics in all Groups

Day of Observation	Group	ΔTP(ms^2)	ΔHF(ms^2)	ΔLF(ms^2)
1st	Group I-B	-253 (-1221–890)	-38 (-241–104)*	-133 (-364–367)
	Group II-B	-49 (-814–462)	-31 (-209–82)	64 (-249–385)
	Group III-B	249 (-367–845)	-113 (-329–(-26))	15 (-162–499)
10th	Group I-B	-101 (-1637–2051)	-190 (-452–161)	-15 (-381–1238)*
	Group II-B	-113 (-1054–1909)	1 (-544–362)	-70 (-558–926)*
	Group III-B	-1005 (-1925–(-271))	-110 (-412–313)	-505 (-1252–44)
1st	Group I-O	159 (-275–854)	-18 (-131–112)#	341 (-86–688)#
	Group II-O	-49 (-784–612)	-25 (-209–65)	-9 (-251–288)
	Group III-O	-265 (-1121–490)	-113 (-351–(-49))	-126 (-495–101)
10th	Group I-O	-476 (-1880–2051)	-38 (-306–384)	-442 (-1111–1278)
	Group II-O	-395 (-1426–1806)	-132 (-542–213)	-15 (-202–825)
	Group III-O	-340 (-953–1452)	-29 (-625–446)	-111 (-555–970)

Note: *p<0.05 in comparison with individuals of group III-B on the respective day of training; #p<0.05 in comparison with individuals of group III-O on the respective day of training: median and interquartile interval 25 and 75%.

On the first day of training the power of HF-component of HRV spectrum decreased in test subjects of all the groups, to a lesser extent in high-performance subjects. The difference between I-B and III-B groups was 75 ms^2 (p=0.04), and between I-O and III-O groups – 95 ms^2 (p>0.05). By the end of training the tendency to reduction of HF-component of HRV spectrum in purposeful activity persisted, however, the intergroup difference of this parameter became statistically insignificant.

On the first day of observation, LF-component of HRV spectrum increased in group I-O, but decreased in group III-O. Thus, the intergroup difference of the studied parameter made 467 ms^2 (p<0.05). By the 10^{th} day of training, LF HRV parameter decreased in all groups. These changes were most expressed in individuals with low speed of performing the tasks and also in individuals with a lesser quantity of mistakes. The difference between I-B and III-B groups made 490 ms^2 (p=0.04), and between I-O and III-Ogroups – 331 ms^2 (p>0.05).

The conducted correlation analysis showed positive correlation of the time parameter with the area of the wave of EMG curve in the initial condition (r=0.48, p<0.001). By the end of observation this interrelation strengthened (r=0.56, p<0.0001). Besides, at this stage of observation the reverse dependence between the time parameter and ΔLF was found (r=-0.24, p<0.05). It is important that at the beginning of the study the quantity of mistakes positively correlated with the area of the wave of EMG curve (r=0.36, p=0.01), but negatively correlated with ΔTP parameters (r=-0.22, p<0.05) andΔLF (r=-0.25, p<0.03). However, by the end of observations the sign of correlation between the number of mistakes and ΔLF changed to positive (r=0.21, p<0.05).

The presented results demonstrate peculiarities of physiological basis of purposeful behavior on the model of endosurgical training in the individuals with different effectiveness of the activity.

It was found that irrespective of the stage of observation, the lesser area of the wave of

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EMG curve calculated in the course of training was characteristic of high-performance individuals. This first of all referred to subjects with a high speed of fulfillment of tasks. A similar level of this parameter in high-performance subjects of different groups was probably due to a common tactics used by these individuals to achieve the result. Lower expenditures of energy on muscle work in a more successful test subjects observed by the end of observations were likely to be associated with formation of specific motor stereotypes. To note, individuals with a different quantity of mistakes made in endosurgical training were characterized by a smaller area of the wave of myogram curve, and, consequently, by a lower muscle activity. This may be attributed to lower physical expenditures on correction of inaccuracies in fulfillment of the tasks.

The total power of HRV spectrum is considered to reflect 'the total reserve of forces' that can be mobilized by an organism to cope with stress load [14,15]. Reduction of the total power of HRV spectrum in subjects with different effectivity in the dynamics of PA that was found in our study, evidences depletion of functional reserves of an organism incase of excessive activation of regulatory mechanisms of the hypothalamo-pituitary system [16].

Spectral power in HF range is one of reliable criteria for assessment of realization of parasympathetic influences on the cardiac activity [14]. It was found by us that at the beginning of observation the most evident reduction of power of the high-frequency component of HRV spectrum in purposeful activity was seen in individuals with lower effectivity. This shows weakening of parasympathetic influences on the functional activity of the heart which may be a consequence of reduction of adaptation resources in the mentioned conditions. The obtained results add to the earlier published data. In particular, a study of T.D. Dzhebrailova, et al. showed that in the course of cognitive activity, high-performance individuals are characterized by dominating influence of parasympathetic nervous system on the work of the heart [6].

Low-frequency oscillations of HRV are known to be associated with the predominant influence of sympathetic division of the autonomic nervous system [14-16]. In our observations, increase in the power of LF component of HRV spectrum was found to be typical of individuals who made the least mistakes on the 1st day of training. The highest stability of power of the lower-frequency component of HRV spectrum in purposeful activity was observed in individuals with a lesser time of fulfillment of the tasks on the 10th day of research. Low-performance individuals were characterized by a statistically significant reduction of LF-component of HRV spectrum both at the beginning and at the end of the training process which demonstrated weakening of sympathetic influences on the cardiac activity at all the studied stages of purposeful behavior. The described regularities generally agree with the existing data on physiological 'cost' of the result of the mental activity of a human [5].

The results of our study significantly extend understanding of formation of basic manual skills in the surgical practice [17]. The obtained data contribute to understanding of systemic mechanisms of regulation of physiological functions of a human in realization of different forms of PA.

Conclusion

It was shown that physiological provision of the purposeful behavior on the model of endosurgical training was different in individuals with different effectiveness of the activity. High-performance individuals were characterized by lower energy expenditures on fulfillment of motor work in purposeful activity. Irrespective of the results, purposeful behavior in the conditions of psychoemotional stress was associated with depletion of the functional reserves of an organism. Low-performance individuals demonstrated a more pronounced weakening of parasympathetic (at the beginning of observations) and of sympathetic (at the end of the study) influences on the functional activity of the heart. Better result in the dynamics of purposeful activity were achieved on the model of endosurgical training at a higher physiological 'cost'.

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