



ORIGINAL ARTICLE

Risk Evaluation of Loss in Professional Efficiency, Health, and Work Safety Using Psychophysiological FactorsValentyn Kalnysh¹, Roksolana Stasyshyn, Marianna Oliskevych^{3*}¹ Department of Aviation and Marine Medicine and Psychophysiology, Ukrainian Military Medical Academy, Kyiv, Ukraine² Laboratory of Labor Psychophysiology, Institute for Occupational Health of the National Academy of Medical Sciences of Ukraine, Kyiv, Ukraine³ Department of Mathematical Economics and Econometrics, Ivan Franko National University of Lviv, Lviv, Ukraine* Corresponding Author: Marianna Oliskevych, E-mail: olisk@ukr.net

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ABSTRACT

Introduction: A transformation in modern production and an increase in workload requires an improvement in the occupational psychophysiological selection, the search for new approaches for its implementation, and the creation of special ways for the evaluation of the psychophysiological state of workers. The aim of this investigation is to develop an approach for the quantitative evaluation of the efficient reduction in risk in worker's occupational activity, and the probability of health and safety depletion during the entire life period of work. **Materials and Methods:** The investigation is based on the data of 110 psychophysiological indicators, received from a survey that encompassed the workers of operative service in electric power engineering industry of Ukraine. The data was examined using statistical tools, factor analysis, and multivariate regression models. **Results:** The developed technique made it possible to determine the statistical significance and to estimate the impact of the important psychophysiological factors on the level of success in the occupational activity of workers under dangerous circumstances. The model includes the variable that describes the age of the worker and provides analysis for 4 categories of ages. **Conclusion:** The important factors that influence the risk of reduction in occupational efficiency of the workers are variability, the total error, and the number of positive values according to the pendulum methodology; the average reaction time according to the square-circle technique; variability according to the square technique; and adaptability and time of the task performance according to the adaptability methodology. The workers belonging to the same age group do not significantly change the risk of depletion in their occupational efficiency.

INTRODUCTION

Modern production, as well as the modern society, is currently being intensively transformed through computerization and robotic production processes. This leads to significant redistribution of workload by reducing the contribution of some work environment factors and increasing those of other sources (1). An increase in the role of dangerous factors requires continuous improvement of professional psychophysiological selection, the search for new approaches and its implementation, and the creation of special ways for the evaluation of the worker's psychophysiological state (2, 3). Emergencies and expert mistakes often arise, not so much from the ignorance of rules of object management, but due to insufficient development of the worker's own psycho-

physiological qualities. As a result, the system "man-machine" operates inefficiently and cannot provide the necessary level of reliability (4). The continuing unsatisfactory and unsafe working conditions have a negative impact on the behavior, health, and safety of workers (5). However, workers who have positive thoughts about their work have healthy lifestyles.

The implementation of modern mathematical techniques helps in the selection of important informative indicators and in aggregating the information about a worker's psychophysiological state to correctly evaluate the efficiency in their professional activity and risks (6). A new technology of video survey was developed to determine the quality of performance of the occupational duties (7). To analyze the most valuable psychological and behavioral characteristics

of a worker, some authors build factor models that are useful in selecting staff (8). The external assessments of the workers' technique proved to be productive for analyzing the efficiency of their professional activity and its connection with psychophysiological characteristics (9). The framework "modular approach" serves to increase the effectiveness of a worker's professional suitability evaluation (10). This technique is based on splitting the initial data into key components; then, the received "modular" information is considered separately with respect to the differences between the data in the selected subgroups. This approach allows to develop some deeper understanding of the role of the individual components underlying the selection procedure and to show their possible interconnection. Some indicators that have an impact on the ability to provide the occupational activities are identified based on factor analysis. Important psychophysiological factors are cognitive abilities, communication and computer skills, physical abilities, interpersonal communication skills, ability to provide security, independence, ability to adapt to the structure of a particular activity, and more specific abilities that are related to the problem performance (11). However, the key factors that cause stress and pressure on the workers of different occupations are different. In the electric power engineering industry, information loading is too important (12). The determination of disabilities emphasizes the importance of psychophysiological selection for the prevention of traffic safety but unfortunately do not provide any solution to get an occupational risk evaluation (13). The quantitative results of such an investigation only affirm that the frequency of errors by female operators is 2.16 times higher than by men.

Regardless of some success in the investigation, we observed a lack of clear quantitative results concerning the risk of loss or depletion in the efficiency of occupational duties during the work life. Furthermore, because of the incomplete investigation of these issues, there are still no approaches for the evaluation of the efficiency in reducing the risk factor in occupational psychophysiological selection. Thus, we need a methodology to evaluate the risks by using a certain number of psychophysiological characteristics. The aim of our investigation is to develop an approach for the quantitative evaluation of the efficiency of risk reduction in a worker's occupational activity, probability of health, and safety depletion during the entire life period of work.

MATERIALS AND METHODS

The problem of professional risk evaluation is diverse. Usually, when we assess this risk, we focus on the risk of health loss. However, there are other sides to this problem. The workers face the risk of performance efficiency depletion. This concept is not so common, but equally important. This risk causes efficiency reduction and is associated with the failures in human activities, as well as reduction in

the occupational activity effectiveness. This reduction in efficiency not only has an economic effect but also provokes mistakes that can lead to disastrous social and environmental consequences. At the same time, the decline in efficiency has a productive effect. It is a reliable indicator of the worker's health and safety depletion. Therefore, the risk of occupational efficiency declining is a more general issue than the risk of health harm.

The present study examined the data of psychophysiological survey by means of statistical tools, factor analysis, and multivariate regression models. Quantitative results were obtained with software EViews 8.0.

At first, we had data for 110 exogenous psychophysiological indicators, received from a survey that encompassed the workers of operative service in the electric power engineering industry of Ukraine. Many of these indicators correlated with each other and reflected similarities between workers information. Taking into account reasonable psychophysiological indicators and preliminary statistical analysis, we selected 31 factors: X10, X11, X12, X14, X16, X17, X18, X2, X22, X23, X24, X31, X32, X4, X40, X46, X47, X50, X54, X55, X57, X7, X8, X83, X86, X88, X89, X9, X90, X91, and X92. The data for these factors were analyzed by means of several psychophysiological survey approaches, especially pendulum, adaptability, and memory methodology; square, triangle, square-circle, triangle-circle techniques; attention switching; clock and closed space techniques, as well as questionnaires.

In order to construct a relevant regression analysis that would adequately evaluate the risk degree of occupational qualities and health depletion, it was necessary to select a sufficiently small number of factors that fully reflect the structure and important relationships within the data. To identify the group of statistically significant factors that affect the efficiency of performing occupational duties of workers in the electric power industry, we used the principal components method at the first stage of statistical analysis. This approach gave us a possibility to explain the covariance relations between the observed variables, based on the formation of the significantly smaller number of unobservable variables, which are called the principal components. We used the psychophysiological health examination data of 466 workers of the operative service in the electric power engineering industry of Ukraine.

We represented n observed physiological indicators for workers X_i as a decomposition of m ($m < n$) unobservable common factors G_i and n unobservable factors caused by random circumstances. The loading matrix L connects unobserved common factors with the observed indicators. Accordingly, the j -th row of the matrix L measures the loading of each main component in the formation of the quantitative value of the observations for j -th indicators. Choosing the optimal number of common factors is an important issue in our research. In the applied literature, scientists use factor analysis for the investigation of various processes. Therefore, they consider different approaches for the identification of the main components. One of the most

commonly used methods for choosing the optimal number of common factors is the Kaiser-Guttman rule. According to this method, the eigenvalues of the unreduced dispersion matrix and covariance matrix of the observed indicators are calculated, and as many common factors as the number eigenvalues that exceed their average value (for the correlation matrix the average of eigenvalues is equal to 1) are considered. Using the Kaiser-Guttman method for the investigation of the depletion risk of professionally important qualities, we produced 11 main components (Fig. 1). Three of the components described 50% of covariance relationships, and 6 components described 80% of covariance relationships (Table 1).

Analysis of the factor loading coefficients for the obtained main factors allowed us to identify the psychophysiological indicators that have the greatest contribution to the formation of the common factors.

Our analysis revealed 12 of the most important variables. Thus, we chose some indicators: X31, X89 that characterize the adaptability and time of task performance, defined by the adaptability methodology; X4, X7, X9, X40 that determine the total error, the number of positive values, the number of hits into zero, and the variability, defined by the pendulum methodology; X18, X55, X57 that characterize the average reaction time, variation and error of the figure skipping, defined by the square-circle technique; X54 that describes the errors, defined by the triangle-circle technique; X83 that characterizes the time of correct solution, defined by attention switching methodology, X47 that determines variability, defined by the square techniques. Now, we looked for obtaining quantitative results for risk based on

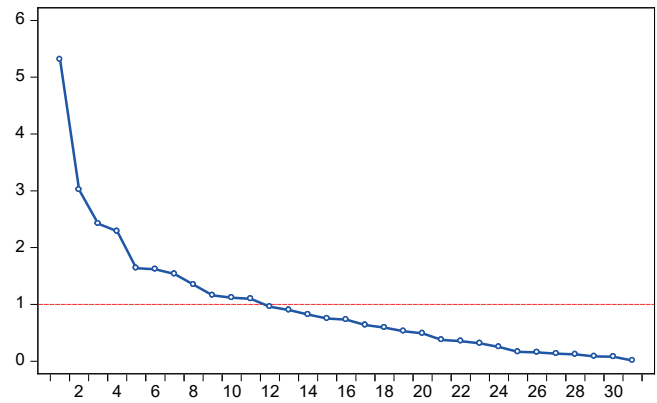


Figure 1. Eigenvalues of unreduced dispersion matrix for a set of observed workers' psychophysiological factors.

Source: authors' evaluation.

this available surveyed observations $f_{1i}, f_{2i}, \dots, f_{12i}$ ($i=1, \dots, N$) for $N=466$ workers.

To achieve the goal of our study, it was necessary to develop a mathematical model for the evaluation of the risk, R , of a critical depletion in the professional qualities of a worker. This risk depends on the set of explanatory factors f_1, f_2, \dots, f_k ($k=12$):

$$R_i = p_i = g(f_{1i}, f_{2i}, \dots, f_{ki}), i = 1, \dots, N. \quad (1)$$

In our study, by examining the psychophysiological characteristics of workers, we cannot observe the actual probabilities p_i . Hence, we created the modeling of the p_i by means of the preliminary observations, y_i , for some aggregated binary variable. Since for each of the 12 selected observa-

Table 1. Dispersion analysis of the estimated main components

Main components	Variation	Cumulative value	Proportion	Cumulative contribution
G1	3.698180	3.698180	0.197161	0.197161
G2	3.621393	7.319573	0.193067	0.390227
G3	2.060457	9.380030	0.109849	0.500076
G4	2.012993	11.39302	0.107318	0.607395
G5	1.487248	12.88027	0.079289	0.686684
G6	1.474679	14.35495	0.078619	0.765304
G7	1.335457	15.69041	0.071197	0.836501
G8	0.996385	16.68679	0.053120	0.889621
G9	0.969819	17.65661	0.051704	0.941325
G10	0.636092	18.29270	0.033912	0.975236
G11	0.464495	18.75720	0.024764	1.000000
Total	18.75720	18.75720	1.000000	

Source: authors' evaluation.

ble indicators, f_j , there is a different scale of measurement, the distributions of these variables have different means and different amplitudes of deviation from the average. Therefore, we used normalization

$$X_{j_n} = (X_j - \text{mean}(X_j)) / (\text{st.dev}(X_j)).$$

where, $\text{mean}(X_j)$ denotes the mean of j -th indicator; $\text{st.dev}(X_j)$ is a standard deviation of j -th indicator. Thus, we defined the variable, indicated the risk indicator Y , which takes 1, if the absolute value of the deviation for some factor exceeds the standard deviation of the empirical distribution, and takes 0 otherwise. Therefore, the value of $Y = 1$ indicates the possibility of having a risk for the particular worker, and the value $Y = 0$ point out the certain absence of risk. For our sample observations for 466 surveyed workers, 319 workers were marked by the value $Y = 1$ and 147 workers were marked by the value $Y = 0$.

In order to evaluate the level of risk for each worker and to form a scale of risk, we estimate the multivariate logit regression model

$$R_i = \text{Prob} \{Y_i = 1\} = F(\beta_0 + \beta_1 f_{1i} + \beta_2 f_{2i} + \dots + \beta_{12} f_{12i} + u_i), \quad i = 1, \dots, N, \quad (2)$$

where, $F(\cdot)$ is a logistic probability function

$$F(x_i) = 1 / (1 + \exp(-x_i)), \quad (3)$$

β is a vector of unknown model parameters that need to be estimated, u is a random element that represents the measurement error and some subjective stochastic factors. The value of R that is close to 1 indicates a high-risk level of depletion in occupational efficiency for the worker. On the contrary, the value of Y close to 0 indicates a low-risk level.

RESULTS

The binary choice model (2)–(3) is a nonlinear regression model that cannot be estimated using the usual least squares method. Therefore, to evaluate its parameters, we used the maximum likelihood method that maximizes the natural logarithm of the likelihood function. To find the numerical

Table 2. Estimation results for the multivariable regression logit model (2) – (3)

Dependent variable : Y

Coefficient Estimation Method: ML – Binary Logit (Quadratic hill climbing)

Convergence achieved after 5 iterations

QML (Huber/White) standard errors & covariance

Factors	Coefficient	Standard Error	t-Statistics	p-value (probability)
C	-8.009159	0.801597	-9.991500	0.0000
F1	1.121119	0.152324	7.360095	0.0000
F2	0.631225	0.093515	6.749989	0.0000
F3	0.227320	0.039166	5.803975	0.0000
F4	-0.498517	0.157379	-3.167625	0.0015
F5	0.244956	0.042043	5.826354	0.0000
F6	0.214471	0.037704	5.688337	0.0000
F7	0.005192	0.001444	3.594657	0.0003
F8	0.201804	0.061436	3.284795	0.0010
AGE_GROUP	0.457110	0.136413	1.444630	0.1486
McFadden R-squared	0.500052	Mean dependent variable		0.315451
Standard Deviation	18.75720	Standard Error of regression		0.313074
Akaike info criterion	1.335457	Sum squared residuals		44.69487
Schwarz criterion	0.996385	Log likelihood		-145.2353
Hannan-Quinn criterion	0.969819	Deviance		290.4706
Restricted deviance	0.636092	Restricted log likelihood		-290.5010
Likelihood Ratio statistic	0.464495	Average log likelihood		-0.311664
Probability(Likelihood Ratio)	18.75720	Total observation		466

Source: authors' evaluation.

values of the parameters, and to maximize this logarithm, we used the Newton-Raffson iterative method.

Table 2 shows the set of the parameters estimated for constructing the logit model, as well as the standard errors, Student’s statistics and probabilities (p-value) that determine the levels of significance, by which the null hypothesis about the statistical insignificance of the explanatory factors is not rejected. The estimated model, in addition to the chosen psychophysiological factors,

$F1 = |X18 - X18mean|$; $F2 = |X83 - X83mean|$; $F3 = |X89 - X89mean|$; $F4 = |X31 - X31mean|$;

$F5 = |X4 - X4mean|$; $F6 = |X40 - X40mean|$; $F7 = |X9 - X9mean|$; $F8 = |X47 - X47mean|$

includes the variable that correspond to the age of worker.

We considered 4 age groups: less than 29, between 30 and 39, between 40 and 49, and more than 50.

We provided the diagnostics of the developed logit model by means of the McFadden coefficient, the likelihood ratio statistic (LR = 290.63), and its corresponding p-value (p-value = 0.0000). We compared the results of the conducted model and the model that takes into account only constants, indicating the benefits of using the logit specification and the adequacy of our modeling (Table 3).

The investigation of the statistical significance of the impact of each factor on the probability of professional suitability of reduction risk is based on Student’s and Wald’s statistics.

Table 3. Diagnostic results for the developed binary logit model

Expectation-Prediction Evaluation for Binary Specification									
Factors	Prob {Y=1}<0.5	Prob {Y=1}>0.5	Correct	Percent correct	E [Y=0]	E [Y=1]	Correct	Percent correct	Percent gain
Developed (4)–(5) Model									
Y=0	293	26	293	91.85	273.9	45.03	273.97	85.88	55.25
Y=1	38	109	109	74.15	45.03	101.9	101.97	69.37	55.25
Total	331	135	402	86.27	319.0	147.00	375.94	80.67	55.25
Model of Constant Probability									
Y=0	319	0	319	100	218.3	100.6	218.37	68.45	
Y=1	147	0	0	0	100.6	46.27	46.37	31.55	
Total	466	0	319	68.45	319.0	147.0	264.74	56.81	

Source: authors’ evaluation.

DISCUSSION

We obtained a statistically significant negative effect of the variable F4 whereas the coefficients for the other significant variables had a positive effect. The obtained estimates indicated an increase in deviation from their average values of the variables, such as the average reaction time (F1), defined by the square-circle technique; the time of correct solutions (F2), defined by attention switching methodology; the time of task performance (F3), defined by the adaptability methodology; cumulative error (F5); variability (F6); and the number of hits into zero (F7), determined by the pendulum methodology; as well as the variability (F8), defined by the square technique. This led to a significant increase in the risk of professional inefficiency and health reduction, and decrease in staff reliability and the readiness to effectively perform duties in difficult or extreme conditions.

Modeling also revealed that workers’ belonging to different age groups is not a statistically significant factor. Therefore, the age of a worker does not significantly affect

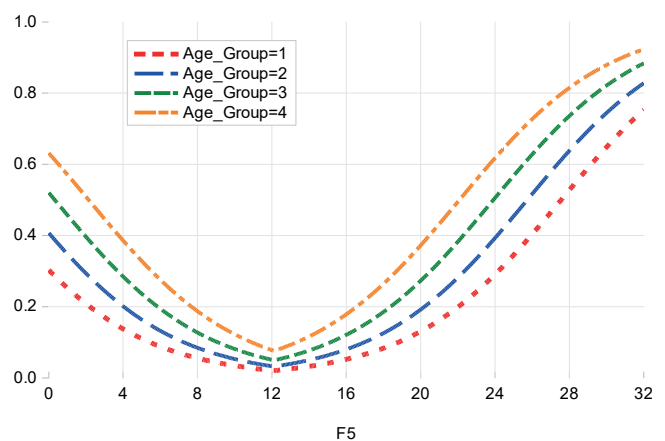


Figure 2. The evaluated risks for different values of cumulative error determined by the pendulum methodology, F5. Source: authors’ evaluation.

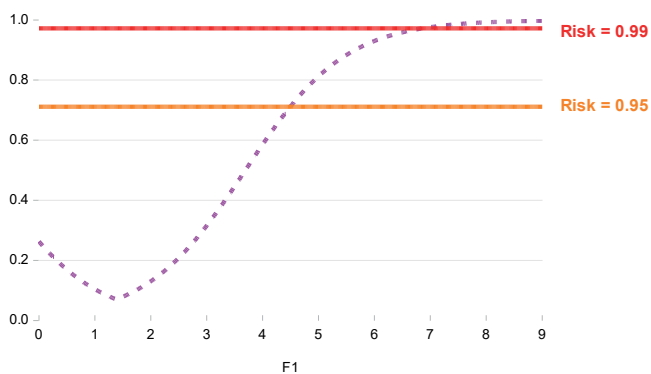


Figure 3. The evaluated risks for different values of average reaction time defined by the square-circle technique, F1. Source: authors' evaluation.

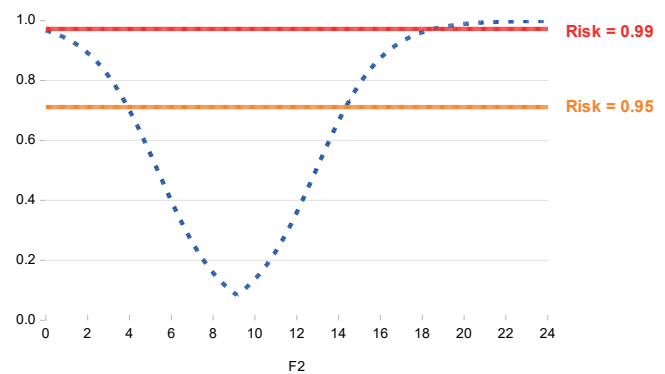


Figure 4. The evaluated risks for different values of average reaction time defined by the square-circle technique, F1. Source: authors' evaluation.

the risk of critical depletion of his occupational qualities and the level of readiness to work, particularly under dangerous and difficult production circumstances.

The simulation results showed that workers with average values of all factors and cumulative errors, determined by the pendulum methodology (F5), regardless of the age group, showed a low-risk level of professional qualities reduction. In contrast, the high deviations from average level of F5 caused an increase in the probability of a negative result concerning the professional suitability (Fig. 2). In addition, the effect on the probability of risk is not symmetric and is steeper and crucial for a positive deviation.

The simulation also revealed the increasing effect of deviation in the average reaction time defined by the square-circle technique, F1, from its average value and the time of correct solutions defined by attention switching methodology, F2 (Fig. 3, 4). In particular, for workers with average values of other factors, the increase of deviation of F1 from its average level (1.5) by 1 point in the corresponding measurement scale of this indicator led to an increase in the risk of professional efficiency depletion by about 24%. Moreover, the precise value depends on the initial level of this indicator and is strongly asymmetric (Fig. 3). On the other hand, the marginal effect of the factor that defines the correct solution time, determined by attention switching methodology, (F2), is almost symmetrical and exceeded the boundaries of risk taking on both sides (for positive and negative deviation from average) (Fig. 4). It was also found that the impacts of these two physiological indicators do not have significant age differences; however, it is more visible for F2 than for F3. Especially for older workers, the time of correct solutions has a greater impact on the depletion of their ability to perform the professional duties effectively compared to younger workers.

The developed multivariate regression logit model (2)–(3) makes it possible to evaluate the risk of occupation qualities depletion for each individual worker based on the information about the observed values of the psychophysiological factors and age.

We calculated the percentage distribution of the workers

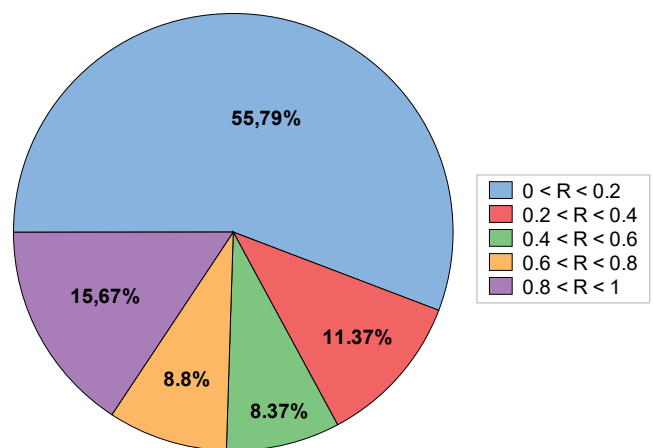


Figure 5. Distribution of the workers of the operative service in the electric power engineering industry after splitting them into 5 risk groups. Source: authors' evaluation.

of 5 risk groups (Fig. 5). The results showed that for almost 56% of the existing workers of the electric power engineering industry in Ukraine, the risk level of professional efficiency loss did not exceed 20%. For 67% of the workers, the risk of effective depletion is less than 40%. However, for over 15% of the workers, we can expect the critical declining of their occupational performance quality with a risk value of more than 0.8. We also evaluated 95% and 99% boundaries of risk taking and estimated that 21% and 6% of the existing workers of energy power sector performed their occupational duties under these dangerous levels of risk in extreme conditions.

CONCLUSION

The risk of reduction and loss in occupational efficiency, health, and work safety for workers significantly depend on seven psychophysiological indicators, determined in our investigation by means of factor analysis approach. We

determined eight important factors, such as the average reaction time defined by the square-circle technique, the time of correct solutions defined by attention switching methodology, the time of task performance by the adaptability methodology, cumulative error, variability, and the number of hits into zero determined by the pendulum methodology as well as the variability defined by the square technique. The simulation results revealed that for workers with average values for all the factors, but with substantive deviation from the average level some of other factors regardless of the age group, we should expect a significant increase in the risk of professional qualities reduction.

Based on our results we can also assert that in the electric power engineering industry, worker's belonging to the same age group do not significantly change the risk of depletion of their occupational ability, health safety, and efficiency.

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NONE

AUTHOR CONTRIBUTIONS

All authors contributed equally in this study.

CONFLICT OF INTERESTS

The authors declare no conflicts of interest.

ETHICAL STANDARDS

The study protocol has been approved by our institutional review board.

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