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Internal-External Parameters' Balance During Cognitive Performance as Measured Individual Adaptive "Norm" for Learning/Training

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ABSTRACT

The paper aims to analysis of relationship between internal and external factors influencing subjects' cognitive test performance and development of the technique to build possible adaptive individual "norm" to the cognitive test performance. The study confirms our hypothesis that human cognitive performance, at least, with simple and repetitive tasks (that are a part of learning process), can be optimized for assessment and prediction of the productive indicators in normal (without time pressure) and under conditions of limited time for task performance using multiple regression models, if to use indices of both physiological support and space-related factors. Subjective psychological indices can be applied as well, but mostly in relation to young people rather than to adults. We believe that such models describe balance during cognitive performance as measured individual adaptive "norm", where the latter can be associated with average productivity over time intervals measured in weeks.

Keywords: Learning, Cognitive Performance, Individual, Adaptive, External factors, Internal factors

INTRODUCTION

As the paper (World Economic Forum, 2025) highlight, amid the rise of artificial intelligence and digitalisation, the most valuable professional capabilities depend on human skills, and not so technical, but human-centric ones. Learning, training, reskilling and upskilling should be effective. The digital transformation of society increases the requirements for the effectiveness of education and training of specialists. At the same time, it is known that the maximum mental performance of a human is achieved with optimal tension of the regulation mechanisms (Yerkes–Dodson law).

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This can be ensured if there is a balance between internal and external parameters of activity (educational/training/work). Taking into account that psychophysiological support of mental activity depends on the individual characteristics of a human, it is possible to consider the existence and use of an individual "norm" of regulation indicators of cognitive performance. Published data clearly demonstrate that parameters of the cardiovascular system and the psychological state can be considered as informative internal parameters (Rico-González et al., 2025). Less studied, but promising for use, are such external factors affecting humans: microclimatic conditions (Dedar Salam Khoshnaw et al, 2025) at the workplace, helio- and geophysical factors (Liddie et al., 2024).

These data suggest that the maximum efficiency of the cognitive performance of a human can be expected if this person can adapt to conditions of activity (including educational), i.e., to balance the internal and external factors of tension regulation mechanisms, that is not a difficult task in individually oriented learning/training and work. In such conditions, it becomes possible to build an individual "norm" of human activity and assess the quantitative measure of deviation from this "norm", which is important for predicting and managing his/her current mental activity.

This paper aims to analysis of relationship between internal and external factors influencing subjects' cognitive test performance and development of the technique to build possible adaptive individual "norm" to the cognitive test performance.

RELATED WORKS

It is well-studied influence of the physical study of young humans and their cognitive performance: heart rate variability (HRV) monitoring can be used as an indirect marker of students' cognitive state and stress response (Solhjoo, 2019); physical activity/cardiorespiratory fitness training programs can positively impact cognitive performance and academic achievement (Nicolini et al., 2024); longitudinal/intervention experimental designs are particularly useful for identifying causal effects. Some similar results in relation to young people were demonstrated in the systematic overview (Rico-González et al., 2025), where authors concluded that "cardiovascular fitness appears to have a positive, albeit complex, relationship with cognitive function and academic performance in youth". Future research should adopt longitudinal and experimental designs to clarify causal pathways. Besides, some studies confirmed (Villringer et al., 2025) that younger schoolchildren demonstrate adaptation of heart rate, vascular tone, and HRV when performing tests on a laptop; this can reflect a physiological response to mental stress. These studies are in line with our previous research (Burov et al., 2021).

In turn, physiological parameters are associated not only with cognitive processes, but also with the external environment, in particular, with climate parameters that influence the human state. In the large review, Bustamante-Mora and colleagues have revealed that weather parameters reduced students' concentration and success (Bustamante-Mora et al., 2025). In A Scoping Review of Systematic Reviews, Roche et al. came to the conclusion

regards the substantial impact of urban exposures on the physical and mental development of children and adolescents (Roche et al., 2024). Kırkıl, G. studied effects of classroom temperature and humidity on student learning performance (kirkil, 2025). It is necessary to highlight that influence of atmospheric influence on a human state and performance were not enough studied up to date, though in our previous research we could reveal such effects (Burov, 2016).

In general, it has been stated that weather changes affected the psychophysiological state, which, in turn, affects cognitive processes and academic performance. Possible mechanisms of influence: at the physiological level - the brain operates in a mode that maintains homeostasis rather than optimally processes information; at the cognitive level - the most vulnerable functions are working memory, attention span, fluctuations in performance, decision-making speed, and decreased tolerance to cognitive load. Empirical studies have shown a decrease in task accuracy, an increase in reaction time and an increase in errors during complex cognitive tasks.

Among the external factors that influence both human health and cognitive activity (which is the basis of learning), cosmic factors (solar- and geophysical) are attracting increasing attention from scientists, foremost in relation to health (Chai et al., 2023). Liddie et al. examined the association between solar activity and the geomagnetic activity index Kp with cognitive outcomes in a large cohort of adults. Their results showed that higher solar/geomagnetic activity indices were associated with an increased likelihood of lower Mini-Mental State Examination scores, but also with higher global cognitive scores for some tests, suggesting mixed effects on different cognitive components. This may serve as direct evidence that space conditions may be associated with variations in cognitive performance across the general population (Liddie et al., 2024).

Kaspranski and colleagues studied the body's responses to changes in the geomagnetic field (GMF) at all scales (even to the weakening of the GMF), including physiological signals in animals and humans, as well as possible behavioral effects (Kaspranski et al., 2025). They have found that even small variations in the magnetic field could cause changes in biochemistry and behavior, although the effects were often varied and highly dependent on specific conditions. In a number of studies, scientists have found that high heart rate variability causes better adaptation to the impact of geomagnetic storms (Ramishvili et al., 2023). The multidirectional nature of the impact on astronauts was also revealed during the study of galactic rays: the effects of galactic cosmic rays on the central nervous system: from negative to unexpectedly positive effects that astronauts may encounter (Kokhan & Dobynde, 2023).

However, it should be noted that: there are very few direct studies in children and students on the influence of cosmic/geomagnetic factors on learning, most studies relate to older populations or animals, often the observed effects are mediated by physiology and not directly measured by cognitive tests, most studies are conducted using a screening method rather than a monitoring one.

METHOD

The methodological basis of our research was a technique based on models and methods for assessment of effective human cognitive test performance. The cognitive test (10-minutes seria of logical-combinatoric tasks of a similar type) has been developed and validated in our prior studies (Burov et al., 2021). Internal indicators included: heart rate variability (HR), their spectrums, vegetative stress index, blood pressure (systolic BPs and diastolic BPd), Self-Activity-Mood indices before the test performance. External indicators stored: solar wind's proton component – rate and density (data from the NASA Internet site); parameters of the geomagnetic field (Ks, A); electron flux, interplanetary magnetic field's and anisotropy indices; atmospheric pressure.

Our study included two subjects' groups: (1) reduced number of indices were registered in tests with 12 subjects (school children of grades 8–10); (2) full number of indices in 10 subjects aged 21–35 (males). All subjects completed the cognitive test 2–3 times a week for 1,5 months; aggregated number of test sessions was 400+.

The adjusted tests block included the numbers' permutation test (combinatorial) in ascending order with two paces. The test material: a sequence of numbers (from 0 to 9) which were not repeated and placed in a random order; the task was to rearrange the numbers in ascending order in a few steps, on each one could only change 2 adjacent numbers. Time for every task performance was free during the 10-minuts test (the next task appeared just after entering the answer), "auto"-pace test T6, and 10-minutes the same tasks' test with fixed time T5 (time for every task was limited and fixed in each session, calculated as an averaged time plus 25%, after the training session). The time of the task performance (Ttp6 and Ttp5 respectively, in milliseconds) and reliability ($\eta 6$ and $\eta 5$) were measured and stored.

The tasks were the same as in our previous research, but the duration was 10 minutes long for each test (T6 and T5) instead of 180 minutes and they were performed one-by-one as a one test session. The daytime was the same for all sessions with no significant variation from 14:00 to 15:00, as well as conditions in the workplace. Thus, all external factors influencing the subjects could be considered the same for everybody. This allows us to study individual responses of every subject's performance and psychophysiological support on mental work. All subjects were highly motivated and could stop participating at any time.

To check the influence of external physical factors on cognitive task performance, solar activity was studied as an external factor possibly impacting human performance. The data on the influence of solar activity on human health and some physiological systems are known (Cherry, 2023), however results of study of cognitive activity associated with solar wind parameters in different activities and different groups of subjects are not presented in scientific literature to date enough. In our early pilot research, the precise connection between effectiveness of operator activity and parameters of the proton component of the solar wind (SW) was revealed in experiments modeling 3-hours operators' work (Burov and Gerasimov, 2005).

We registered indices of proton component of a solar wind speed SWsp (km/s) and density SWden (proton/см^3) in time of the test session. Besides, we stored parameters of the solar wind and seria of helio-physic indices as follows: proton density and speed; electron flux (Ef) in bands 47-68, 115-195, 310-580, 761-1220 and 1060-1900 KeV; indices of the interplanetary magnetic field Bx, By, Bz and Bt; anisotropy index AnI. Those indices as well as parameters of the geomagnetic field (GMF) - planetary index Ks, index of "equivalent amplitude" A, were stored from the site NASA (Instruments on ACE 2024). Atmospheric pressure was registered as an external factor.

The tests and measurements techniques were similar to our previous research as validated, but methods of data analysis differed according to the goal of this research. The main difference is normalizing row data to unify scales of measurement.

Because our research involved human subjects, they signed the informed consent of participants, their personal data were excluded from the research' database, and their participation in the research was coordinated and approved by their institutional authority. Preliminary, it has been acquired the approval of the National Committee for bioethics of Ukraine to conduct such research.

RESULTS AND DISCUSSION

The indices analysed in this study have different nature (physiology, cognitive test performance, subjective evaluation, atmospheric pressure, helio-physics and geomagnetic field) and scales of measurement. Because we studied influences of the internal and external parameters on a human cognitive performance and self-assessment of the current state, we normalized all indices by scale "1" to unify assessment of indices in such a way: "raw" scores for each indicator were recalculated as the ratio of the current value to the maximum measured value. A distinctive feature of our approach was that we assessed cognitive performance based on the productivity indicator for the corresponding test, which was calculated as the ratio of the reliability coefficient to the time it took to solve the test problems. This productivity indicator (W5 and W6 accordingly test type) was also normalized, but relative to the average value rather than the maximum (as an approximation to the individual "norm"). Thus, all indicators were converted to a scale from 0 to 1.

To determine the correlation between cognitive test performance by school pupils (speed Tl6 and reliability η6) and physiological parameters (mean and spectral components of the VLF, LF, and HF heart rate), solar wind and GMF parameters, as well as subjective assessments, we used multiple regression analysis with a forward stepwise selection of the most informative variables to include in the model. As shown in our previous studies, 3-5 parameters are sufficient for a robust and informative model.

In this research, we have revealed that multiple correlation factors of the average time of test performance (Tl5 and Tl6) were moderate (< 0,6) with the significance p≤ 0,05 across the entire group of subjects (12 people) and all test performance days (12-15 for each). The "missing" testing days were

due to the peculiarities of the schoolchildren's academic schedules. The most informative variables were mostly subjective self-assessment ones and speed of the solar wind. Not a high correlation can be explained by the "blurring" of the data due to interindividual differences in physiological support and subjective assessments of the participants.

However, individual analysis demonstrated significant ($p \leq 0{,}01$) and higher relationship between productivity indicator W6 and independent variables ($R = 0{,}65 \ldots 0{,}96$). The informative variables were subjective self-assessment ones (mood, attention) and speed or density of the solar wind varying between subjects. Physiological indices were absent in models that could be explained by a wide variation of inter-person physiological features in adolescent age.

The main conclusion of this study is significant inter-person variation of the relationship of the cognitive performance indicators and their internal and external parameters in young people. Gender differences, particularly in adolescent physiology, may further contribute to the variability in results. This may be why subjective assessment indicators (mood, attention, anxiety) were more informative than others, making the balance between internal and external factors less stable.

Considering this result, further research was aimed at achieving the stated goal in a monitoring study on a group of young men without the participation of adolescents. The technique of the data analysis was the same, but number of external parameters was extended and included not only indices of the solar wins and GMP, but other indices described in the chapter "Method".

The main idea of this research was to check if the highest productivity would have a stable and high correlation with both indices of physiological regulation, psychological self-assessment and external factors, and what indices were selected to such models at individual and group level. We included in analysis a seria helio-physics indices and build regression models. It is known some relationship between helio-physic indices used in our study (Chakraborty et al., 2024), but they had non-linear nature and multiple regression analysis could be applied correctly.

The selection of the most informative independent variables has shown that productivity indicator of cognitive test performance had very high correlation with those indices from registered ($R = 0{,}76 \ldots 0{,}95$ in the test T6 and $R = 0{,}78 \ldots 0{,}97$ in the test T5) with $p \leq 0{,}001$. The difference in relationship can be explained by individual features of subjects, as well as the difference in the selected into models a set of the most informative indices. The common feature of all models was the inclusion of external parameters, first of all, solar wind density SWd, anisotropy index AIn and total strength of interplanetary magnetic field Bt. Heart rate HR and blood pressure systolic indices from physiological ones were the most representative in the biggest part of models. What was significant, self-assessment indices were not represented in models excepting only one case in contrast to study with young people.

The main conclusion related to this subject group is that productive indicator of the cognitive test performance has clear and high relationship

with both internal and external parameters of examined activity. This finding can be recommended to be used in intelligent adaptation method for human-machine interaction in E-Learning systems.

CONCLUSION

The study confirms our hypothesis that human cognitive performance, at least, with simple and repetitive tasks (that are a part of learning process), can be optimized for assessment and prediction of the productive indicators in normal (without time pressure) and under conditions of limited time for task performance using multiple regression models, if to use indices of both physiological support and space-related factors. Subjective psychological indices can be applied as well, but mostly in relation to young people rather than to adults. We believe that such models describe balance during cognitive performance as measured individual adaptive "norm", where the latter can be associated with average productivity over time intervals measured in weeks.

LIMITATIONS OF THE STUDY.

In this research we have studied human cognitive performance in terrestrial conditions where the geomagnetic field defenced humans from the space factors' effect. The cognitive performance has been studied in relation to relatively easy logical-combinatoric tasks without time pressure and with the fixed time limit for the task performance closed to the individual average time of the subject with free rate. Besides, the test duration of every type was ten minutes long. The duration of the monitoring of the cognitive test performance by subjects was limited by 1,5 months.

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