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A Technical Device for Determining the Predispositions of Students—Air Traffic Controllers and Pilots during Multitasking Training

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Featured Application: Authors are encouraged to provide a concise description of the specific application or a potential application of the work. This section is not mandatory.

Abstract: The specific professions of aviation personnel include the professions of the pilot and air traffic controller. These occupations are specific in that while performing their work, they must be able to simultaneously operate the devices in the handling area and in the pedipulation area, supplemented by acoustic sensations in the form of correspondence between flying and ground stations. The performance requirements of pilots and air traffic controllers place high demands on their health, psychological condition, attention, and concentration, due to being in constant pursuit of minimization of erroneous decisions, otherwise defined as the human factor in aviation. This article is focused on the development and testing of a technical device for measuring the relative error rate of students in multitasking tasks in preparation for employment. The main result is a designed technical device with hardware (HW) and software (SW) parts. An experimental method was used to measure the qualitative and quantitative performance indicators of the test subjects. The results of the experiment were observed and evaluated based on the analytical-synthetic method based on critical thinking. By comparing and abstracting the measured data, the reference values of the performance indicators of the tested subjects were determined. The selection of the final sample of subjects consisted of two phases. In the first phase, questionnaires were evaluated, and in the second phase, reaction time measurements during multitasking tasks using technical equipment were evaluated. Based on the measurements, an error ratio was defined, which could be graphically represented. The testing proved the full functionality of the designed technical equipment for these purposes in aviation education.

Keywords: transport; human factor; aviation education; experiment; reaction time

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1. Introduction

At the Department of Flight Training of the Faculty of Aeronautics of the Technical University of Kosice (TUKE), together with representatives of other departments of the Faculty of Aeronautics and institutions outside TUKE, the project "Application of self-regulatory methods in the training of flight crews" was implemented. The project dealt with human performance in air transport in the profession of the pilot and its impact on the safety of air transport. This is a very topical issue, as there is currently a constant increase in requirements for aviation professions, not least for the mental and physical activity of aviation personnel [1]. This implies the need to identify individual factors affecting aircrew, such as fatigue [2], discomfort, maneuvering under certain loads, or flights in adverse weather conditions, which in some way cause stress and thus affect the psychophysiological parameters of aircrew and consequently the quality and safety of flights [3]. Despite statistical evaluations of air transport, as the safest mode of transporting passengers and cargo, current air accidents and the increase in air traffic with their capacity problems are causing significant global interest in aviation safety, including human performance [4,5]. Some authors in their studies are devoted to the forecasting and flow of shipments, evaluating safety in transport. The aim of these studies is to predict the short-term and long-term prediction of traffic flow [6]. Most studies in this area deal with the mental strain of aviation personnel, which, given its disproportionate size, can lead to imperfect perception, insufficient attention, or an insufficient level of information processing. These stressors negatively affect air safety, in which statistical indicators point to the fact that the human factor currently plays a key role in most air accidents [7]. One of the first studies in this area was conducted in 1977 at an airbase in Arizona, in which researchers focused on the origin and effect of stress in pilot training [8]. Their research was based on research studies that showed the effect of stress on changes in the effectiveness of pilot behavior, thus leading to an increased possibility of making wrong decisions. Similar studies have shown the origin and presence of stress when flying, respectively, during simulated flights [9,10]. However, other studies have focused on evaluating the impact of stress and its factors concerning professional activities. Various factors of life have been examined, such as relationships, family problems, lifestyle, etc. [11]. The findings pointed to the need to intensively organize control or stress management programs, which result in the improved operational efficiency of aviation personnel [12]. An interesting study by Y. Lin et al. describes the training of air traffic controllers using computerized pseudo-pilots, including speech and language recognition, thereby trying to eliminate factors affecting flight safety [13]. In a study by Wilson and Fisher, several physiological parameters were measured in pilots, which aimed to define the load in individual flight segments [14]. The aim was to find suitable physiological parameters and their combination for determining the condition (pilot load rate) concerning flight segments [15,16]. Most current studies have used several parameters to assess mental and physical stress, such as heart rate, respiratory rate, eye click, myopotentials, temperature, blood pressure, etc. [17,18]. However, the evaluation of the parameters realized in the previous studies was based on different methodologies of data collection and evaluation using different types of sensors [19]. Topics are found in both military and civilian aviation training; for example, in the work of the Advisory Group for Aerospace Research and Development (AGARD) on assessment of pilot workload [20]. French pilots are trained in modern avionics and learning to scan views into and out of the cockpit, for both their decision-making processes and errors, are under investigation [21]. We can study, from a selected literature review, the Eye-Tracking Measures in Aviation [22] or flight tests for a proof of concept and to compare the reaction times of pilots looking out the cabin and pilots looking at the display [23]. Work on the design of a portable measuring device for measuring the reaction time of the upper limbs and lower limbs to visual stimuli is also inspiring [24,25]; for example, reaction time measurement devices for flight crew testing [26], especially for 24 h flights. We can study the prediction of a pilot's reaction time based on EEG signals [27] or based on visual perception [28].

In the years 2012 to 2015, the project "Research of pilot training methods using flight simulators", co-financed by European Union resources within the Operational Program Research and Development, which was assigned the code 26220220161, was successfully implemented at the Faculty of Aeronautics. Within the project was gained new knowledge in the field of the impact of changes in the display of flight and navigation data on pilot performance and air safety. The subject of the research was to compare the performance of pilots in changing the display of information in the cockpit from the classic display to the glass cockpit. Within the research, the performance of the pilots was measured using the accuracy of piloting techniques and load levels. Today, although the issue of load assessment in the aviation professions seems to be largely overhauled, we do not record established methods for assessing physical and mental stress, and especially in real air traffic, there are no methods for eliminating load and increasing performance that would apply to various types of professions providing air transport. The previous scientific work was the motivation for continuing to investigate the issue.

For the needs of the project, it was necessary to create a device, which is presented in this article. The device for measuring reaction time in multitasking tasks simultaneously evaluates inputs from the manipulation, pedipulation, and acoustic environments in real time. With the device for measuring reaction time in multitasking tasks, it is possible to determine the critical point of the measured subject's psychological readiness for the performance of a specific occupation. The newly created device integrates newly created software and available hardware devices that can be used in the conditions of the Slovak Republic.

The specific professions of aviation personnel include the professions of pilot and air traffic controller. These occupations are specific in that, while performing their work, they must be able to simultaneously operate equipment in the handling area and in the pedipulation area, supplemented by acoustic sensations in the form of correspondence between flying and ground stations. The performance requirements of pilots and air traffic controllers place high demands on their health, psychological state, attention, concentration, due to being in constant pursuit of minimization of erroneous decisions. When measuring the reaction time for multitasking tasks, which are the output of the designed device, it is possible to monitor the performance of the individual and the deviations in the monitored indicators from the reference values during repeated tests. Such monitoring of performance parameters could help practical training of instructors, such as through individual counseling, thus enabling an individual approach in the theoretical as well as practical training of pilots and air traffic controllers.

This facility is unique in the territory of the Slovak Republic. There are similar devices for measuring reaction time in the world, but they are not made specifically for the needs of monitoring the correctness and speed of reaction during the performance of the profession of pilots and air traffic controllers. The device designed by us, unlike other devices, monitors the speed and correctness of the response in the manipulation space and pedipulation space simultaneously, with acoustic sensations. This covers the entire spectrum of activities of the professions of pilots and air traffic controllers.

The device for measuring reaction time in multitasking tasks used in this work is the subject of the Industrial Property Office of the Slovak Republic as a utility model SK 8986 Y1 and is the subject of a patent application PP 50007-2020. The main goal of the paper was to design and test a technical device for measuring the relative error rate of students—air traffic controllers and pilots—during multitasking training in aviation education.

We studied two research questions:

Research question 1: Is it possible to produce a technical device for measuring the relative error rate of the test subject using the measurement of reaction time when solving multitasking tasks?

Research question 2: Will the testing of the technical device demonstrate the ability to compare the relative error rate of the tested subjects?

The main result is a designed technical device enabling the measurement of the relative error rate of the tested persons when solving multitasking tasks, which is made up of the relevant HW and SW parts. This paper emphasizes an innovative approach to testing and evaluating student performance in preparation for the aviation profession. The technical solution is protected by copyright on the registered utility model, logged at the Industrial Property Office (the Section 6). Experimental testing of the technical device under the conditions provides at the Faculty of Aeronautics demonstrated the full functionality of the designed device, with use in aviation education.

The paper is structured as follows: In the next part, the HW and SW of the technical device are presented. The third part presents the results of the validation experiment, which was primarily focused on testing the device. Finally, first experiences with the performance of the proposed technical device are discussed, focusing on the new perspectives provided by this scientific work.

2. Materials and Methods

2.1. Methods and Methodology

For the processing of the article and the processing of the issue, an analysis of available studies and scientific works was carried out using the analytical-synthetic method based on critical thinking. During the selection of a sample of students, a questionnaire method was used to determine the entry requirements for conducting the experiment. In the experimental phase, a verification device was used to determine the predisposition of aviation personnel based on the measurement of reaction time in multitasking tasks. When evaluating the qualitative and quantitative indicators of the measured data, the methods of observation, induction, deduction, comparison, abstraction, and generalization were used. The detailed procedure of the experimental testing is shown in Figure 1.

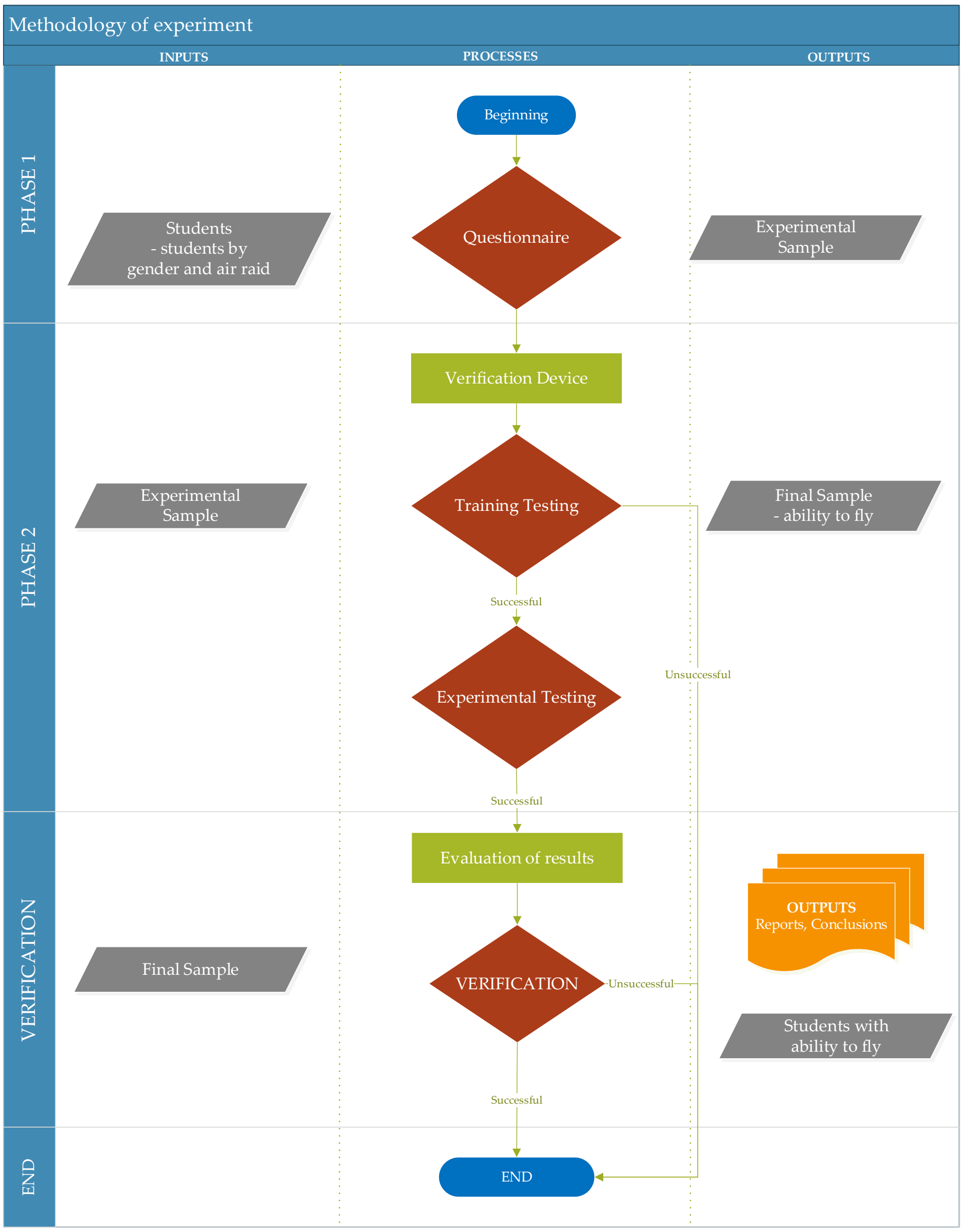

Figure 1. Algorithm of the testing process.

The device, which was used to measure the reaction time during multitasking tasks, was developed at the Faculty of Aeronautics, TUKE, and is the subject of the utility model PUV 50011-2020, which was published in the Gazette and Registered at the Industrial Property Office of the Slovak Republic. The device can process acoustic commands and tasks from the handling and pedipulation area in real time. The device was developed to determine the predisposition of individuals to perform the profession of the pilot and air traffic controller. The verification device monitors the speed of the test sample, the correct motor function, and the response to visual and auditory stimuli.

2.2. Testing Device Hardware

The device used to test the chosen subjects is shown in Figure 2. The device itself is durable and easily transportable. The device is made of durable materials, such as aluminum and hardened plastic, which ensures the protection of the delicate electronics inside the device. The device in its disassembled state is placed in a transport case, which ensures easy handling and transfer of the device. The dimensions for inclusion in transport condition (Figure 3) are 35 × 25 × 17 cm. It consists of four main parts: the main module, with the integrated microcontroller (MCU) module and buttons placed in front of the tested subject, and from the foot pedals, a module that connects to the main module, as well as one from the headphones. The main module is connected to the USB port of a PC or a laptop that has the software application running and from this port it is also powered. The USB connection provides a virtual comport connection with a baud rate of 921,600 baud/s, 8-bit word, and one stop bit without parity.

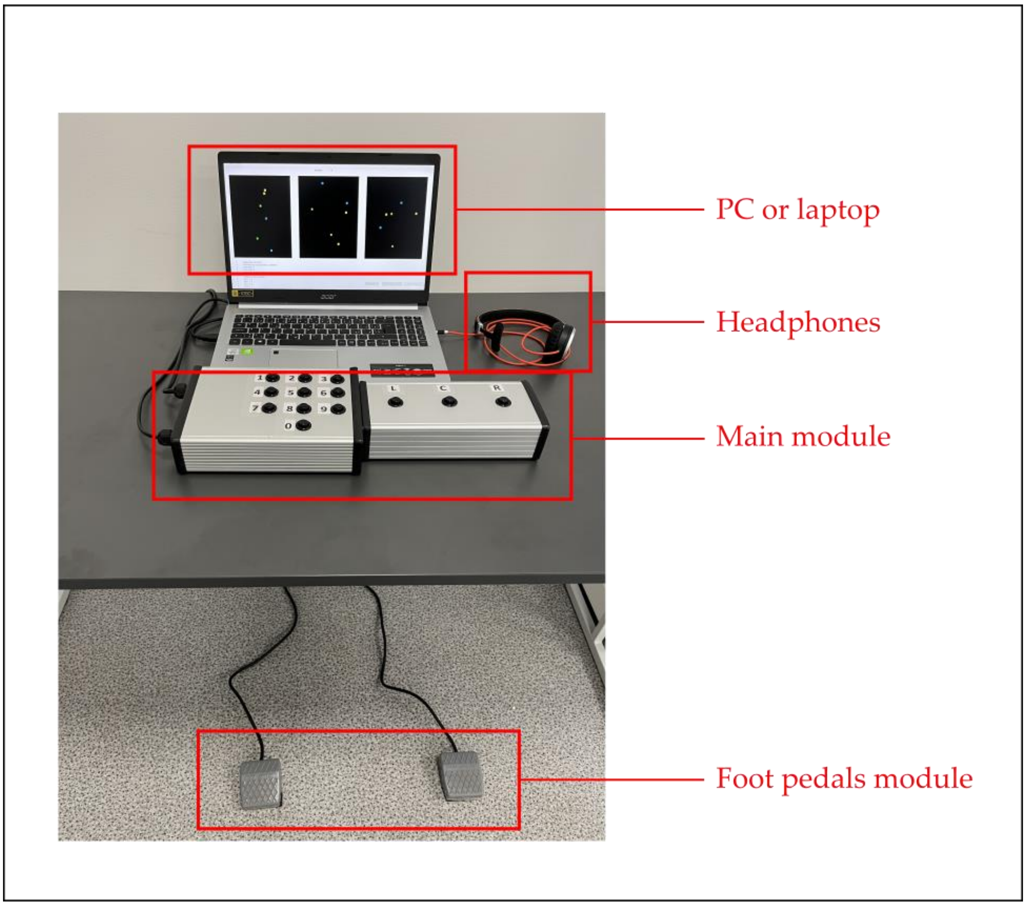

Figure 2. Photo of the testing device.

Figure 3. The testing device in transport conditions.

The MCU uses an embedded module with NXP LPC1768 processor that is based on the ARM Cortex-M3 architecture and is running at 96 MHz. It has 32 KB RAM and 512 KB FLASH memories, which are sufficient for the tasks programmed in the C programming language that realize within the testing system. All the buttons, both the ones for visual (3 buttons) and for audio (10 buttons) tasks, and both pedals are connected to the MCU with pull-up resistors to define the initial state and suppress the possible interference from ambient electromagnetic fields.

There are no timers used within the MCU; it simply reacts as fast as possible to in-puts and sends them to the PC or laptop; however, the button groups are logically handled as buses, to avoid accepting the situation in which more buttons from the same group are simultaneously pressed. Each button has its corresponding ASCII character from “a” to “o”, which is sent if it is pressed, and to avoid sending multiple characters, the button needs to be released and again pressed to send another character; thus, the buttons are evaluated after a state change is detected. The safety time margin, when the buttons are non-responsive while the task changes from one type to another, was set to 0.2 s. When testing the device, it was found that the minimum response speed was measured at 0.3 s, and the device testing also showed that the buttons oscillated for up to 0.1 s, causing errors in the measurements. For this reason, the software set a minimum task time of 0.2 s, and the problems with the oscillation of the probes were thereby eliminated.

The main result of the work is a technical device for measuring the relative error rate of students—air traffic controllers and pilots—during multitasking training, which consists of HW and SW parts. The basis of the measuring device is a suitably located input–output unit, which is connected in connection with the handling control unit. The manipulation control unit also includes buttons L, C, and R, which are used to enter tasks from movements entered in the manipulation area. Other signals entering the manipulation control unit are imported from the numeric keypad, containing buttons 0–9, which are used to enter the tasks of the acoustic commands. The tasks resulting from the pedipulation area enter the control unit from the left pedipulation unit and the right pedipulation unit. The verification device was designed to measure the reaction time in response to a randomly generated task. The technical solution of the device is shown on Figure 4.

2.3. Testing Device Software

The application software for the testing device was written in the C++ programming language in the QtCreator IDE with help of the QtFramework libraries. The main window of the application is shown in Figure 5. The window is divided into three main regions, excluding the region for the control buttons information text region and three graphic regions.

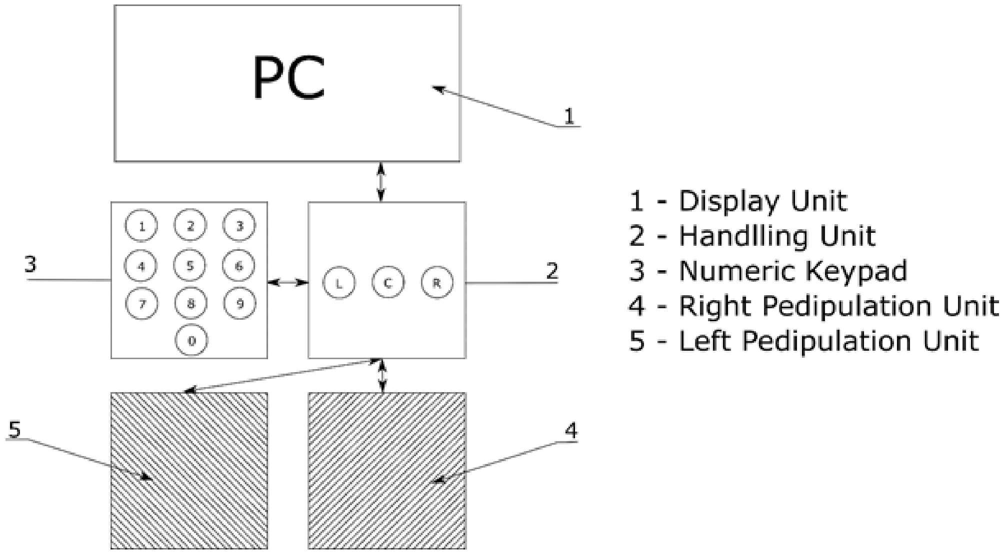

Figure 4. The technical solution of the device for measuring the reaction time and the relative error rate in multitasking tasks.

Figure 5. Main window of the application of the testing device.

The settings dialog window is shown in Figure 6. Parameters that can be set include the working directory, in which the output files are created, and the base name for the created files. Considering the testing process, the number of testing cycles can be set, and since the number of tasks in one cycle is 6, this setting can be adjusted only as multiples of 6. The last adjustable setting is the COM port name to properly choose the connected testing device MCU.

There are 3 timers/counters used in the application: the first measures the time to complete the task, the second ensures moving to next task after 20 s, and the third is responsible to play a chosen audio sound repetitively, each being 2 s, up to 9 times in one testing cycle.

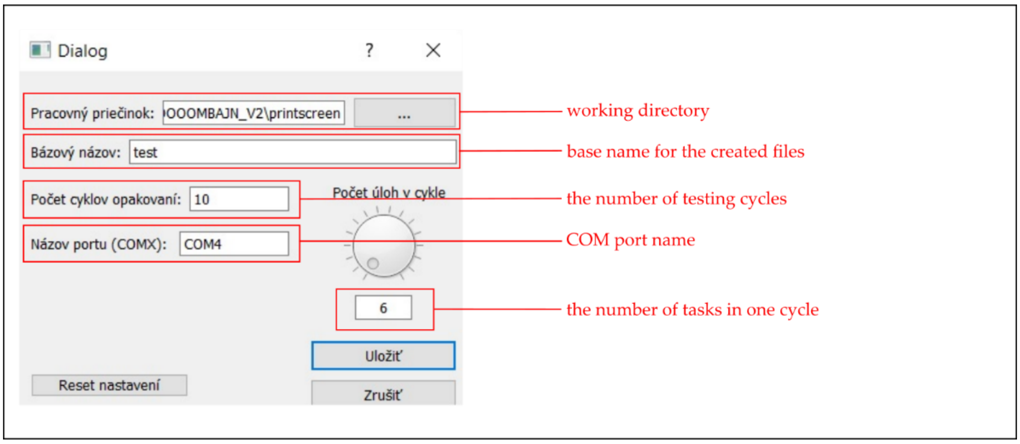

Figure 6. Settings window of the application for the testing device.

The three graphic regions serve to draw small squares while the red square, if it is drawn in a region, has a special meaning (see the Results section). The tasks generated for testing one subject are created randomly within the sets of 6 into a complete sequence of tasks in an array. Other sub-arrays used in the application include the arrays filled during this process with randomly generated colors (yellow, green, blue) and with identification of one from the three sectors of each graphic region randomly chosen for the approaches if needed. All the randomization processes are seeded with an unsigned int value of the current time and is handled at the start of the testing, so the generation process does not interfere with the testing process.

The example output file of the testing is shown in Figure 7. As it can be seen, it is a formatted text file that has chosen statistical parameters in the head of the file at lines beginning with the "#" character. The statistical parameters include the complete time taken to finish the testing, average time for one task, total number of tasks, total number of errors, and the error ratio parameter. The last six lines indicate the values to create a histogram, with task type number on the x-axis and the errors corresponding to each task type on the y-axis.

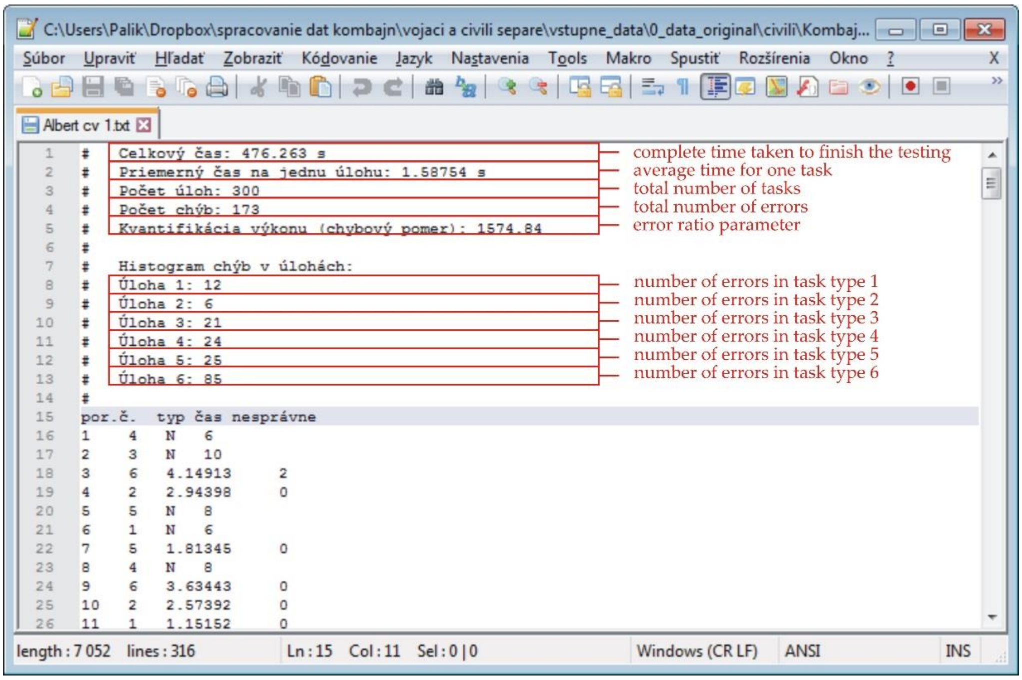

Figure 7. Output file example.

After the head there are four columns, which form from left to right they are the number of the task within the testing, the task type number, time in seconds, and the number of errors for the given task.

3. Results and Experimental Testing of Device

3.1. Testing Process

The device generates six random tasks, where the ratio of the individual types of tasks is determined as follows:

- Tasks 1–3 are focused on visual perceptions and stimuli to which the test subject responds in the manipulation area. The main goal of these tasks is to reveal the predisposition of the tested subject to work in a specific profession and to determine the speed and correctness of the reactions to visual perceptions and stimuli at the standard load of reactions in the handling area. The secondary goal of these tasks is to determine the ability of the test subject to respond to visual stimuli with different wavelengths; i.e., whether the test subject has corrected color vision.
- Tasks 4–5 are focused on visual perceptions and stimuli to which the test subject responds in the pedipulation area. The main goal of these tasks is to reveal the predisposition of the tested subject to work in a specific profession and to determine the speed and correctness of responses to visual perceptions and stimuli at the standard load of reactions in the pedipulation area. The secondary objective of this task is to determine the ability of the test subject to engage opposite hemispheres of the brain.
- Task 6 is focused on acoustic perceptions and stimuli to which the test subject responds in the manipulation area. The main goal of this task is to reveal the predispositions of the tested subject to work in a specific profession and to determine the speed and correctness of reactions to acoustic perceptions and stimuli of reactions in the handling area. The secondary objective of this task is to determine the ability of the test subject to respond to multiple types of tasks simultaneously.

Another research part of the project aimed at testing the technical equipment took place in two stages. When creating the test sample, it was necessary to ensure the representation of women. All volunteers interested in participating in the project had to fill out a questionnaire (identification data, age, gender, experience with aircraft piloting—real and simulator). The initial requirement for inclusion in the test sample was zero experience with piloting the aircraft. In the next part of the selection, those interested in participating in the project passed a stress test and tested their performance using a device for measuring reaction time. This selection aimed to exclude from the experiment those subjects who exhibit higher emotional lability, low ability to concentrate, and reduced ability to perform several activities simultaneously under increased load, which should ensure greater uniformity of the test sample and increase the objectivity of experimental results. From various entrance tests, which help to determine the health and mental fitness of an individual to perform a given profession, we focused on monitoring and measuring the reaction time of selected subjects within the entrance tests. Current devices used to measure reaction time are widespread throughout the world, especially in the military, in the departments of general psychology and sports. Within the reaction time measuring device, simple tasks for measuring the reaction time can be used, for example, "Go/No Go" tasks to explore higher brain centers, or more complex tasks to measure critical response time to explore cognitive processing skills. Reaction time is genetically the most conditioned, which means that it can be least developed through training. Reaction time belongs to the structure of the motor skills. We can divide it into simple, when an individual responds to one stimulus, or complex, when there can be several stimuli to respond to. The reaction time consists of several characteristics. The most important characteristic is its level represented by the response time itself. The higher the reaction time, the shorter the response time.

After starting the test, three sectors with a size of 300×600 pixels are displayed on the display unit. In each of the sectors, three pairs of dots (yellow, green, blue) with a size of 10×10 pixels are displayed. A pair of dots of the same color are 150 pixels apart. With the start of each new six tasks, the system automatically triggers a beep at regular 2-second intervals. The number of beeps must be counted in parallel in addition to solving other tasks. After entering the correct number of beeps, the system considers the beep cycle complete and begins generating beeps again as the six new tasks begin. The display unit of the device for measuring the reaction time is shown on Figure 8.

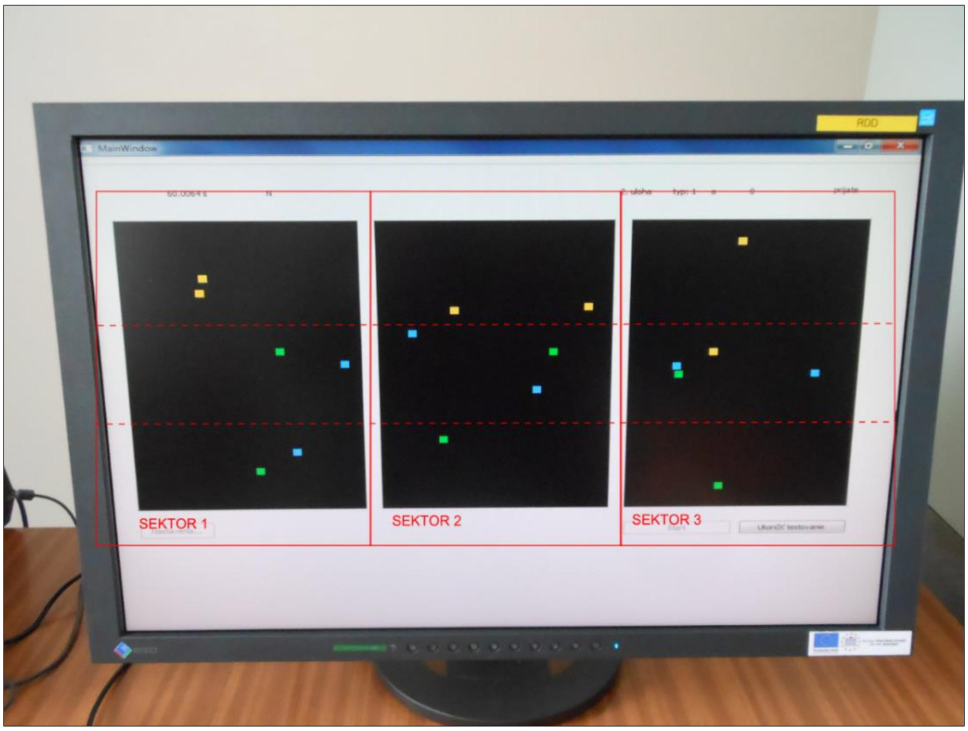

Figure 8. The display unit of the device for measuring the reaction time and the relative error rate in multitasking tasks.

The verification device system will generate a new task only after entering the correct answer. The test subject thus has real-time feedback. If the correct answer is not entered within 20 s, the system generates another answer and writes the letter N (unfulfilled task) to the file instead of the time.

Within one testing, the system generates 50 six-task errands, and the tested subject must correctly answer the 300 individual tasks focused on visual and acoustic perceptions. The output of testing is a data file containing the following:

- Total time to complete 300 tasks.
- Average time per task.
- Total number of errors.
- Frequency of errors in Tasks 1–6.

Task 1—in Sector 1, Sector 2, and Sector 3, three pairs of dots (yellow, green, blue) 150 pixels apart are displayed. However, in Sector 1, one pair of points of the same color has a distance reduced to 30 pixels (two points of the same color converge). The correct answer for Task 1 is to press the L button in the manipulation area.

Task 2—in Sector 1, Sector 2, and Sector 3, three pairs of dots (yellow, green, blue) 150 pixels apart are displayed. However, in Sector 2, one pair of dots of the same color has a distance reduced to 30 pixels (two dots of the same color converge). The correct answer for Task 2 is to press the C key in the manipulation area.

Task 3—in Sector 1, Sector 2, and Sector 3, three pairs of dots (yellow, green, blue) 150 pixels apart are displayed. However, in Sector 3, one pair of points of the same color has a distance reduced to 30 pixels (two points of the same color converge). The correct answer for Task 3 is to press the R button in the manipulation area.

Task 4—in Sector 1, Sector 2, and Sector 3, three pairs of dots (yellow, green, blue) 150 pixels apart are displayed. However, one red dot appears in Sector 1. The correct answer for Task 4 is to press the right foot in the pedipulation area.

Task 5—in Sector 1, Sector 2, and Sector 3, three pairs of dots (yellow, green, blue) 150 pixels apart are displayed. However, one red dot appears in Sector 3. The correct answer for Task 5 is to press the left foot in the pedipulation area.

Task 6—in Sector 1, Sector 2, and Sector 3, three pairs of dots (yellow, green, blue) 150 pixels apart are displayed. However, one red dot appears in Sector 2. The correct answer for Task 6 is to press the number 0–9 in the manipulation area, which belongs to the number of beeps. The maximum number of beeps in the software is limited to 9. Examples of tasks are shown on Figure 9.

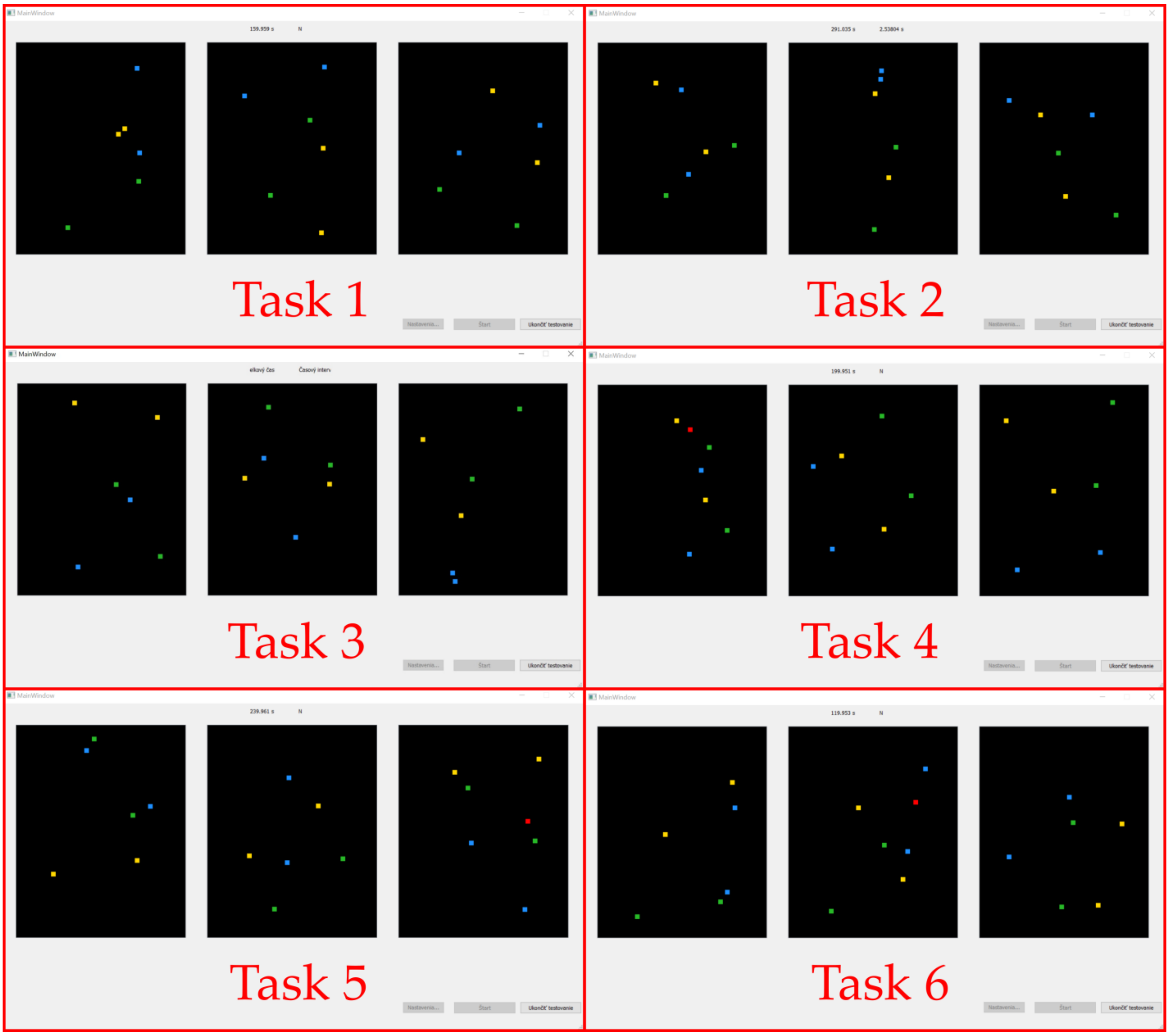

Figure 9. Kind of tasks during testing.

3.2. Evaluation of the Second Phase of Testing

Sixty-seven subjects participated in the testing. During testing, the total time required to perform a set of 300 randomly generated tasks and the number of incorrect answers during testing were monitored. The limit for inclusion in the project was set for a total time equal to a maximum of 600 s, which is a limit of 2 s for one task and the maximum number of errors was set at 50. These values were proposed based on expert estimation and practical experience in the trial testing process and can inform further research. The time limit out of the 67 subjects tested was met by 56 subjects. A total of 42 subjects met the limit for the maximum number of errors. A total of 38 subjects met both conditions. The measurement results are shown in the Table 1.

Table 1. Reaction time measurement results.

Id. Number	Total Time (s)	Number of Errors	Id. Number	Total Time (s)	Number of Errors
1	519.915	81	35	318.023	16
2	487.075	34	36	429.547	29
3	547.572	95	37	452.071	19
4	490.938	11	38	555.681	90
5	487.372	14	39	543.032	33
6	577.624	37	40	425.296	12
7	762.946	39	41	814.409	24
8	507.443	68	42	595.353	130
9	420.878	19	43	530.984	81
10	511.277	10	44	412.196	31
11	562.873	40	45	782.842	17
12	431.982	34	46	711.697	146
13	514.599	80	47	480.365	41
14	590.016	61	48	543.561	60
15	598.243	144	49	577.845	4
16	556.69	77	50	451.344	49
17	603.676	63	51	613.209	33
18	487.603	10	52	587.756	45
19	472.704	89	53	569.494	24
20	418.209	17	54	730.159	215
21	556.69	77	55	546.573	17
22	414.943	24	56	559.433	34
23	564.363	45	57	635.107	172
24	559.49	73	58	630.072	104
25	555.52	17	59	545.311	119
26	576.967	18	60	433.763	17
27	501.158	22	61	536.571	34
28	590.132	49	62	470.849	23
29	489.205	38	63	431.998	42
30	477.607	26	64	579.464	82
31	488.833	22	65	464.728	45
32	517.261	54	66	698.726	79
33	592.02	29	67	890.012	133
34	571.148	58			

3.3. Selection of the Final Sample for the Project

During controlled flights on the aircraft-to-ground radio connection. Pilots are controlled using the "Hearback/Readback" system. This means that each instruction from the air traffic controller must be repeated correctly. Only after the correct repetition of the instruction can they start to follow the instruction. In case of an incorrect command from the air traffic controller, or incorrect repetition of the instruction by the pilot, the instruction "Correction" follows and the whole instruction is sent anew both by the air traffic controller and the pilot. Therefore, in the error rate, the weight of one incorrect answer is expressed as four times the average time per roll. The error ratio, therefore, has the following final form:

$$ER = AT \cdot (NT + 4 \cdot NE) \quad (1)$$

where:

ER = error ratio;
AT = average time for one task in seconds;
NT = number of tasks;
NE = number of errors.

For the limit values of the total time (600 s) and the total number of errors (50), the limit value of the error ratio would be ER = 2.(300 + 4.50) = 1000. A total of 43 subjects met this filter. Based on the error rate, a ranking of the best entities that could be worked on in the project was compiled. As the number of reported students far outweighed the need for a test sample of the project, we were able to tighten the error rate criteria during the measurement of reaction time by 20% to the level of 800 points, from which we received a final sample of 30 subjects + one substitute. The final ranking is shown in the Table 2.

Table 2. The final sample of subjects.

Id. Number	Total Time (s)	Total Errors	Error Ratio (Count)	Id. Number	Total Time (s)	Total Errors	Error Ratio (Count)
35	318.023	16	385.868	11	562.873	40	863.072
40	425.296	12	493.344	51	613.209	33	883.021
20	418.209	17	513.003	32	517.261	54	889.689
9	420.878	19	527.5	23	564.363	45	902.981
60	433.763	17	532.083	52	587.756	45	940.409
22	414.943	24	547.724	45	782.842	17	960.286
18	487.603	10	552.617	8	507.443	68	967.525
4	490.938	11	562.943	28	590.132	49	975.686
37	452.071	19	566.596	48	543.561	60	978.41
5	487.372	14	578.349	34	571.148	58	1012.84
10	511.277	10	579.447	19	472.704	89	1033.65
44	412.196	31	582.57	13	514.599	80	1063.51
36	429.547	29	595.638	14	590.016	61	1069.9
49	577.845	4	608.663	41	814.409	24	1075.02
62	470.849	23	615.242	1	519.915	81	1081.42
12	431.982	34	627.814	24	559.49	73	1104.06
31	488.833	22	632.224	43	530.984	81	1104.45
30	477.607	26	643.177	17	603.676	63	1110.76
27	501.158	22	648.164	16	556.69	77	1128.22
55	546.573	17	670.463	21	556.69	77	1128.22
63	431.998	42	673.917	7	762.946	39	1159.68
25	555.52	17	681.437	64	579.464	82	1213.01
2	487.075	34	707.883	38	555.681	90	1222.5
26	576.967	18	715.439	3	547.572	95	1241.16
29	489.205	38	737.069	59	545.311	119	1410.54
47	480.365	41	742.965	66	698.726	79	1434.72
65	464.728	45	743.565	58	630.072	104	1503.77
50	451.344	49	746.223	42	595.353	130	1627.3
53	569.494	24	751.733	15	598.243	144	1746.87
61	536.571	34	779.816	57	635.107	172	2091.62
39	543.032	33	781.966	46	711.697	146	2097.13
56	559.433	34	813.042	67	890.012	133	2468.3
33	592.02	29	820.934	54	730.159	215	2823.28
6	577.624	37	862.585				

4. Discussion

In evaluating the data, emphasis was placed on the total time required to perform tests on the device for measuring reaction time in multitasking tasks, on the total number of errors during testing in individual subjects and on the number of errors in individual types of tasks.

Time to complete the test is shown on Figure 10 and Histogram of time to complete the test is shown on Figure 11.

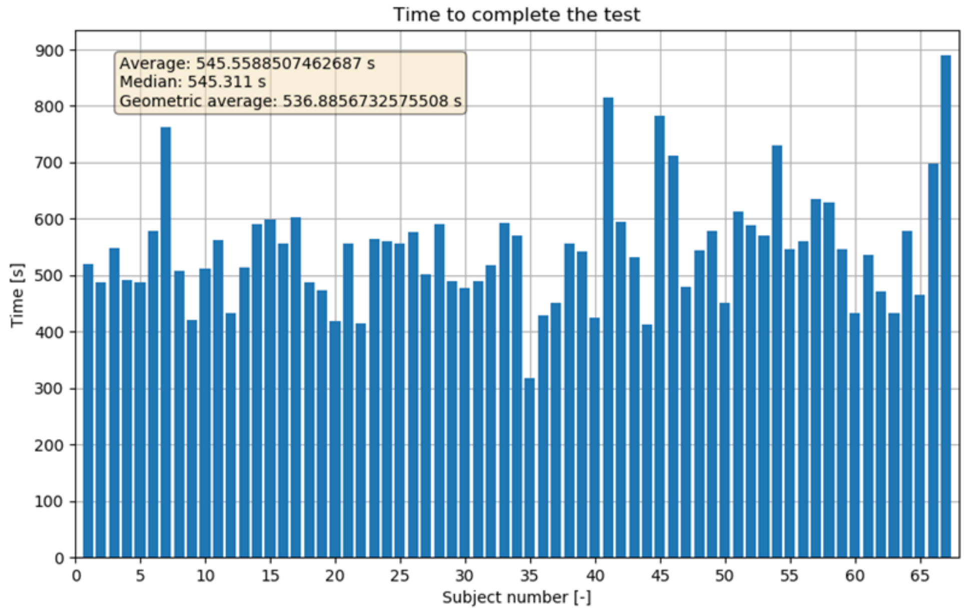

Figure 10. Time to complete the test.

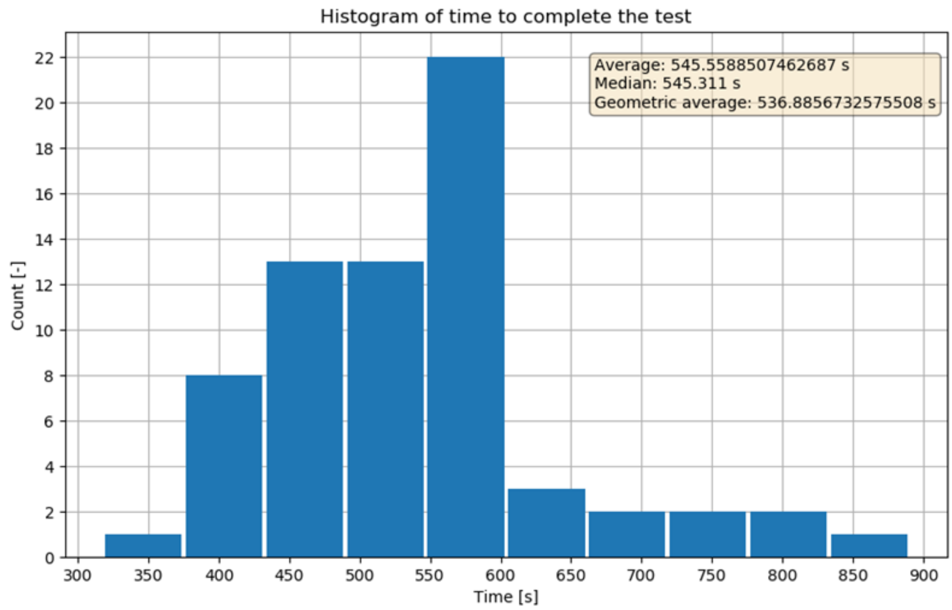

Figure 11. Histogram of time to complete the test.

From the graphs showing the total time required to complete the testing, it can be observed that most of the tested subjects were able to perform the tasks in the time limit of 440 s to 600 s, i.e., 48 subjects, which is approximately 71.5% tested; 10 subjects were not able to meet the time limit, and 9 subjects passed the test under 440 s.

Cumulative number of errors is shown on Figure 12 and histogram of the cumulative number of errors during the test is shown on Figure 13.

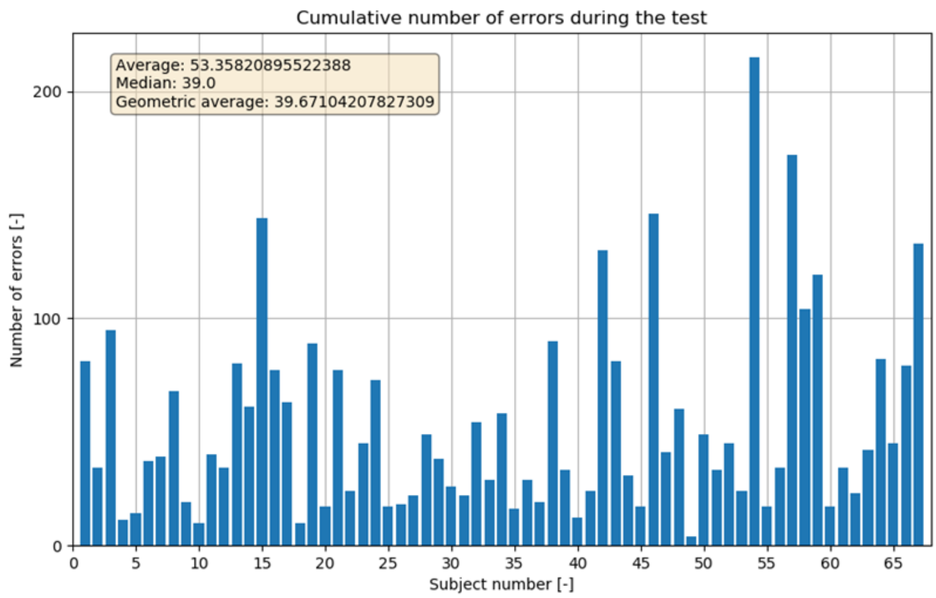

Figure 12. Cumulative number of errors during the test.

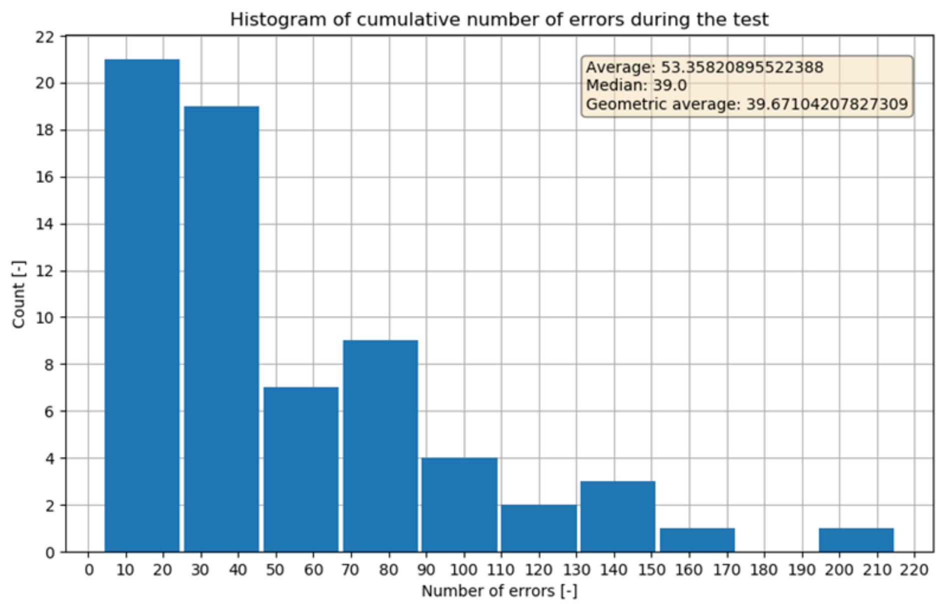

Figure 13. Histogram of the cumulative number of errors during the test.

From the graphs of the total number of errors during the test, each test subject made at least one error. There was no case without error. Less than 45 errors were made by 40 subjects, which is approximately 59.7% of the number of subjects tested. When comparing the times and number of errors in subjects with the longest test time, a correlation is not clear; Subjects 7, 41, 45, 46, 54, 66, and 67 needed the longest test times, but a significant correlation was observed only for Subjects 54 and 67.

Subjects with the lowest number of errors (4, 5, 10, 18, 40, and 49) reached times of less than 500 s, except for Subject 49, who reached a time of approximately 578 s, but this subject made the fewest errors (4) of all subjects. Looking at the overall test group, it can be observed that most of the tested subjects fall into two groups—fast-reacting, but with a higher error rate, and slower reacting, with a lower error rate.

Figure 14 shows the number of errors based on the type of tasks – per subject. For better readability of picture, different types of tasks are marked with different colors. The Figure 15 shows percentage fraction of errors based on type of tasks – all subjects together.

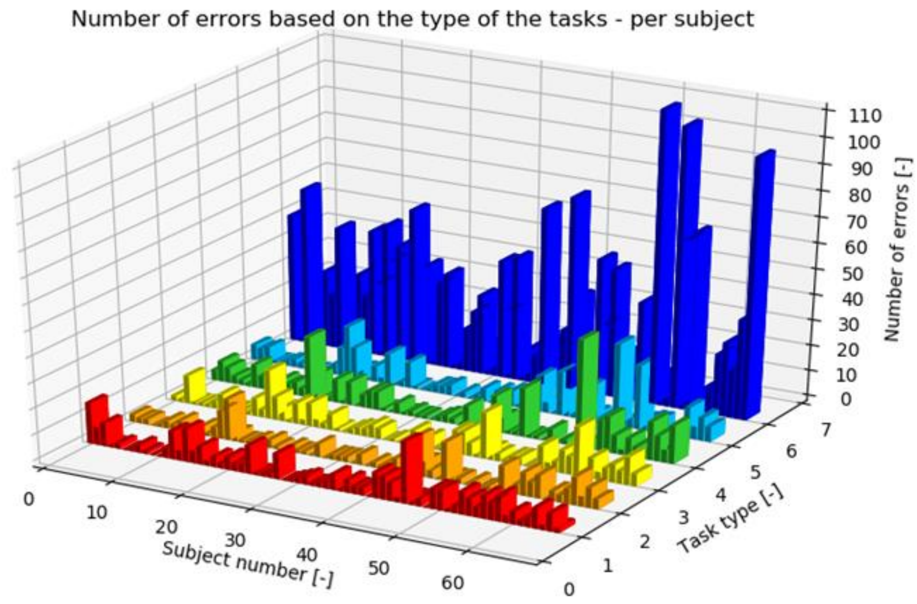

Figure 14. Number of errors based on the type of tasks—per subject.

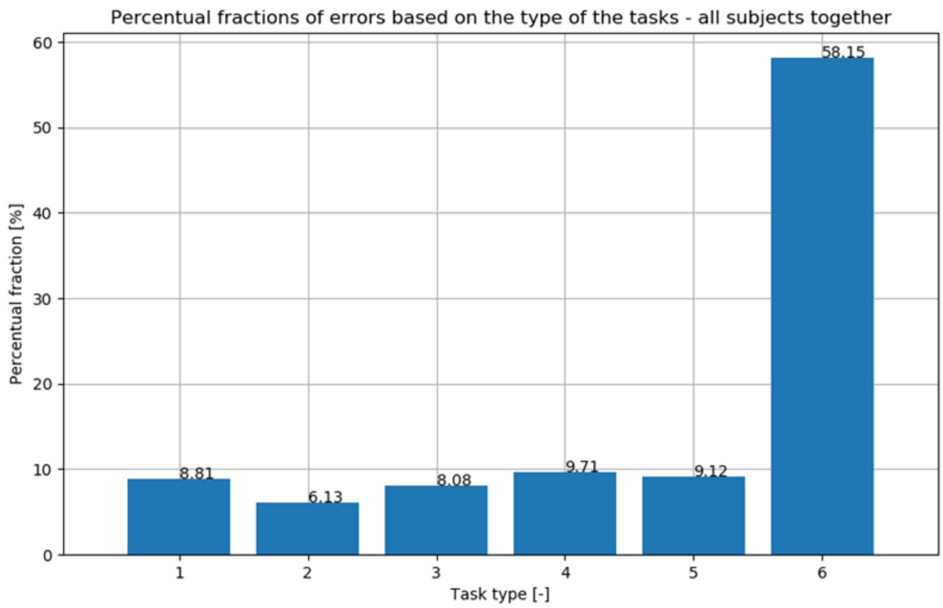

Figure 15. Percentage fraction of errors based on the type of tasks—all subject together.

From the graph (graphs) of the frequency of errors for individual tasks, the biggest problem was the test subjects with a task focused on parallelism; i.e., determining the correct number of sound stimuli when up to more than 58% of errors were in this task. This is one of the most important tasks in testing because even during real air traffic, this task is performed by the pilot in parallel. During the flight activity itself (monitoring of altitude, course, speed, engine speed), a pilot must watch in parallel (non-stop) the appropriate radio frequency, follow the instructions of air traffic control, and those of the instructor. From the visualization of the number of errors in the type of tasks "per subject", specific cases can be observed where the error rate for the "audio" parallel task was minimal, but the error rate in other tasks was increased. The same phenomenon can be observed in these test subjects as in the group that made quite a few mistakes in the "audio" task, thus showing weak multitasking skill. Subjects who made mistakes in a task of any type cannot respond properly to multiple stimuli at the same time, as they have trouble engaging both hemispheres of the brain, which can have fatal consequences in real air traffic.

As described in Section 3.3., during controlled flights on the aircraft–ground radio link, the pilots are controlled using the "Hearback/Readback" system. This means that every instruction from the air traffic controller must be repeated correctly. Only after correct repetition of the instruction can they begin to follow the instruction. In the event of an incorrect command from the air traffic controller, or an incorrect repetition of the instruction by the pilot, the instruction "Correction" follows, and the entire instruction is sent anew to both the air traffic controller and the pilot. Therefore, in the error rate, the weight of one wrong answer is expressed as four times the average time per hour, which has a fundamental impact on the final shape of the relative error rate. By calculating the relative error rate of the tested persons when solving multitasking tasks in training, the result of our scientific work differs from the results of the works discussed in the literature search, primarily those of [25–28].

5. Conclusions

The purpose of the article was to present a device for measuring reaction time in multitasking tasks and to verify the functionality of its connection. The device, which was used to measure reaction time during multitasking tasks, was developed at the TUKE Aviation Faculty and is the subject of utility model PUV 50011-2020, which was published in the Gazette and Register of the Slovak Industrial Property Office, which ensures its uniqueness in the conditions of the Slovak Republic. The device designed by us monitors the speed and correctness of the response in the manipulation space and pedipulation space simultaneously, with acoustic sensations. This covers the entire spectrum of activities of the professions of pilot and air traffic controller.

The methodology of the experimental research was based on the implementation of testing in two phases. In the first phase, a questionnaire method was used to eliminate students who did not meet the conditions of the experimental research. In the second phase, testing took place on the verification device to determine the predispositions of the adepts to perform the aviation profession.

During testing, the total time required to perform a set of 300 randomly generated tasks and the number of incorrect answers during testing were monitored. The limit for inclusion in the project was set for a total time equal to a maximum of 600 s, which is a limit of 2 s for 1 task and the maximum number of errors was set at 50. The time limit out of the 67 tested subjects was met by 56 subjects. A total of 42 subjects met the limit for the maximum number of errors. A total of 38 subjects met both conditions.

After evaluating the questionnaires, and measuring the reaction time for multitasking tasks, a final test sample was determined, which participated in the project activities. In the aviation profession, the right decision is more important than the speed of the decision. During testing on the verification device, more emphasis was placed on the correctness of the response than on the speed of the response.

The so-called error ratio was determined for the objective assessment of the current mental preparedness. The error rate expresses the dependence of incorrect answers, reaction time, and the total number of tasks. In the error rate, the weight of one incorrect answer is expressed as four times the average time per task. Based on the error rate, a ranking of the best subjects was compiled. Based on the ranking, 31 entities were involved in the project activities, with which it was possible to work in the project.

The creation of the device was based on commonly used materials and equipment in aircraft cockpits and at air traffic control stations, such as display units in the form of a monitor, buttons on a computer keyboard, control elements of the aircraft cabin in the form of buttons, and pedal systems commonly used in aircraft cabins and at air traffic control stations. To make the experiment as reliable as possible, the device simulates the actions of pilots and air traffic controllers in real operation.

By measuring the reaction time of the monitored sample, the correctness of the connection and operation of the device was confirmed. The device for measuring the reaction time in multitasking tasks, which is used to select the final sample of adepts, can be used to stabilize methods for assessing physical and mental stress in real and simulated air traffic to eliminate the load and increase performance. The results of the measurements may apply to different types of professions providing air transport.

6. Patents

The device for measuring reaction time in multitasking tasks used in this work is registered at the Industrial Property Office of the Slovak Republic as a utility model, SK 8986 Y1, and is the subject of a patent application, PP 50007-2020.

Author Contributions: Conceptualization, M.A.; methodology, M.A. and P.L.; software, M.A. and P.L.; validation, P.L.; formal analysis, M.A. and P.L.; investigation, M.A. and P.L.; resources, M.A.; data curation, M.A.; writing—original draft preparation, M.A. and P.L.; writing—review and editing, M.A. and P.L.; supervision, M.A.; project administration, M.A.; funding acquisition, M.A. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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