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Contemporary Approaches to Assessing Psychomotor Efficiency: A Study in Sports Psychology and Transportation

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ABSTRACT

The current study explored contemporary approaches to assessing psychomotor efficiency in sports psychology and transportation. The study's significance lies in the increasing demand for precise methods to evaluate psychomotor skills, essential for enhancing athletic performance and optimizing safety in transportation. The study involved 1007 participants from the Kuyavian-Pomeranian Voivodeship, categorized by gender and age. Methodologies from the Psychophysiological Variable Measurement Polypsychograph System, including Addition Tests, Number Test, Line Test, Simple Coordination Test, and Complex Coordination Test, were analyzed. The results emphasize robust test reliability and reveal noteworthy correlations. Pearson correlation coefficient values, intra-class correlations, and test-retest reliability (Rtt) substantiate method efficacy, ranging from 0.59 to 0.92. Interdependence between Raven's matrix tests and the Psychophysiological Variable Measurement Polypsychograph System methods affirmed the applied method's validity in assessing cognitive facets of efficiency. Additionally, substantial correlations between reaction time using traditional indicators and computerized counterparts demonstrated the validity of the method in the motor aspect. The current study provides essential insights for sports psychology and transportation. The discussed diagnostic tools are crucial for scientific inquiry and diagnostic applications, particularly in the precise selection of individuals with heightened psychomotor proficiency.

KEYWORDS

psychomotor assessment
sports psychology
reliability analysis
validity evaluation
diagnostic tools

INTRODUCTION

The assessment of psychomotor and cognitive efficiency constitutes an indispensable element in various fields, such as sports psychology (Kiss & Balogh, 2019; Ong, 2015; Przednowek et al., 2019), transport psychology (Tarnowski, 2021), neuropsychology (Steinke & Kopp, 2020), e-sports (Horoszkiewicz et al., 2022), as well as aviation (Thomas et al., 2021; Uchroński, 2020) and recruitment for military operations (Paśko et al., 2022). As these scientific areas continue to develop, there is a growing demand for research methods that enable precise and effective assessment of such abilities (Sumińska et al., 2023).

In scientific literature, the concept of "psychomotor skills" often undergoes various interpretations (Biernacki & Tarnowski, 2008; Chaiken et al., 2000; Ree & Carretta, 1994), and in some publications, the definition of this term can even be lost (Dilnoza, 2023). The word "psycho" refers to psychological properties (Horoszkiewicz et al., 2022), while the word "motor" literally means movement (Dilnoza, 2023). Psychomotor efficiency is a process of functioning that encompasses cognitive aspects, such as perception and thinking, as well as executive aspects, namely, motor responses (Horoszkiewicz et al., 2022). These spheres are interconnected, making it difficult to precisely separate one from the other in tests requiring motor responses. We can define it as an interaction between mental processes and motor skills. Conversely, cognitive efficiency refers to the ability to effectively process information, make decisions, and solve problems.

In various fields, high psychomotor efficiency plays a crucial role. For example, in sports, high effectiveness in this aspect can be decisive for athletic success (Burhanuddin et al., 2021; Habay et al., 2021; Wilczyńska et al., 2021), while in aviation, it may directly impact the safety and effectiveness of operations (Thomas et al., 2021; Uchroński, 2020). Additionally, studying psychomotor efficiency can lead to a better understanding of learning processes and the speed of adaptation to new tasks, which, in turn, can contribute to improving the effectiveness of diagnosis and therapy in areas such as neuropsychology and rehabilitation.

In the current market reality, there are few available tools that meet these requirements, making the topic exceptionally significant and relevant. Reliability refers to the extent to which a given measurement method generates repeatable and consistent results. A properly chosen method

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should be able to achieve a high level of reliability, eliminating the possibility of random errors (Koo & Li, 2016). However, in the case of assessing psychomotor efficiency, the challenge lies in finding methods that are both reliable and allow for a quick and accurate assessment.

Similarly, validity refers to how accurately a measurement method represents the phenomenon or characteristic being studied (Koo & Li, 2016). Valid methods ensure that the results of psychomotor efficiency assessments reflect reality rather than random factors or measurement errors. However, there is disagreement among researchers regarding this approach. Schimmack (2021) proposes that a proper validation research program should adopt a multi-method approach and utilize causal modeling with structural equation models. Expressing reliability in quantitative terms is crucial, with temporal stability being one aspect.

In constructing test matrices for addition tests and simple and complex coordination tests, Kahneman's (2017) concept of fast and slow thinking was employed. Fast thinking involves automatic responses to simple mathematical actions, like adding single digits, representing tasks with low difficulty. For example, quickly answering "4" when asked the result of 2 + 2 demonstrates fast thinking. Slow thinking, on the other hand, is required for solving complex mathematical problems that demand deeper analysis and calculation. For instance, solving equations like (35 × 12) - 48 necessitates more time and effort, corresponding to slow thinking and requiring conscious mental effort.

In a simple coordination test where subjects type the displayed number on a computer screen using a keyboard, quick and intuitive responses to stimuli are crucial. Conversely, in a complex coordination test where subjects input the result of mathematical operations displayed on the screen, such as addition or subtraction, besides thinking speed, the ability to perform complex cognitive operations and visual-manual coordination is significant. The theory of fast and slow thinking helps analyze test results, providing insights into how various cognitive factors influence reaction speed and accuracy.

According to Kerkhoff (2000), visual functions are vital in various activities, including patient mobility, binocular vision, depth perception, reading, and language processing. Vision is a crucial source of information for memory and an essential medium in the workplace, particularly in today's visually-oriented world with significant reliance on computer technologies. In the context of the line test, which relies on precise visual recognition and interpretation, the role of visual functions in daily tasks becomes even more critical. Subjects need to focus their attention on the task to quickly and accurately count lines, requiring a transition to a more focused and conscious perception process. Task efficiency may also depend on the ability to concentrate attention on specific elements of the image, which can be challenging for individuals with visual impairments.

Neisser's (2014) assumptions suggest that performing the line test involves not only consciously counting lines but also an earlier stage of automatic visual perception, which may pose greater difficulty for individuals with visual impairments. Indicators of visual search efficiency include reaction time (RT) and accuracy, which vary depending on changes in the set size – the number of elements on the computer screen.

Tasks related to the number test are based on Treisman and her colleagues' theory of visual search from the 1970s (Treisman & Gelade, 1980). Visual search tests require participants to quickly locate a specific object among others. For instance, on a computer screen, an image containing multiple letters (or, in the case of the Polypsychograph System, multiple two-digit numbers) may appear, and participants must identify specific characters (e.g., the number indicated by the computer) as swiftly as possible. This test assesses the speed and efficiency of visual processing and the effectiveness of searching for specific elements.

In the context of various fields employing methods for assessing psychomotor and cognitive efficiency, there is a need for the development of innovative tools that meet these criteria. The validity and reliability of psychomotor assessment play a crucial role in evaluating the psycho-physical condition of athletes, drivers, pilots, and other individuals whose work involves high cognitive demands and loads. Sports psychology relies on the application of methods for assessing psychomotor efficiency to identify athletic talents, monitor training progress, and predict sports performance. In neuropsychology, valid and reliable measurement methods are essential for diagnosing and monitoring disorders of psychomotor functions, such as dyspraxia or coordination disorders. In aviation, the validity and reliability of psychomotor efficiency assessment are crucial for the safe and effective functioning of pilots and crew members who must make rapid decisions and respond to changing weather conditions and emergency situations.

With the advancement of technology and an increasing understanding of the complexity of human functioning, new research methods are emerging (Sumińska et al., 2023). In addition to traditional psychomotor and cognitive tests, simulators, and wearable technologies, there are innovative approaches that allow for a more precise and effective assessment of human efficiency in various areas. An example of such an approach is the Psychophysiological Variable Measurement Polypsychograph System, which integrates psychomotor assessment with other aspects such as personality traits, temperament, and stress coping (Horoszkiewicz & Horoszkiewicz, 2022). However, it should be emphasized that currently, there are few research methods on the market that meet high standards of reliability and validity in assessing psychomotor efficiency. There is therefore an urgent need for further development and improvement of these tools to ensure more accurate and reliable results.

As the methodological foundation of the System, the microgenetic theory of brain function, popular in recent years, developed by the American neurologist and neuropsychologist Jason W. Brown (1989), has been adopted. This theory enables the understanding and interpretation of changes in both thinking and behavior resulting from various diseases, the pharmacological agents used in their treatment, and the processes associated with aging (Brown, 1989). A key aspect of the microgenetic theory is the focus on a dynamic process that continually evolves, undergoing successive modifications. In contrast to other approaches that seek to describe the static state of the subject, Brown's microgenetic theory encourages the description of the evolution process experienced by the individual. In this context, the observed state (symptom) is not considered an error or incorrect task execution but rather a correctly performed action at a more primitive level (Korchut & Horoszkiewicz, 2018). According to Brown, as the brain learns, it reorganizes its resources, allowing "centers of specialization" to gradually assume responsibility for functions they perform most effectively. This is analogous to how evolution adapts organisms to changing environmental conditions. The specialization of brain function also evolves ontogenetically, meaning that as individuals age, more specific functions concentrate in relevant brain regions. This explains why focal damage in the same locations can lead to entirely different symptoms in younger individuals (Walsh & Darby, 2008).

In a microgenetic approach, events progress in a single direction, akin to the processes of evolution or development. Microgenesis entails the transition from one cognitive level to another, with the key being the movement from one level to the next, potentially resulting in the emergence of new features and properties. However, distinguishing between what constitutes a level versus a transition can pose challenges.

The issue of the stability of psychological levels revolves around whether they are fixed elements of mental structure or are influenced by specific psychological events at any given moment. Brown (1989) suggests considering this issue in relation to memory. Recalling past experiences involves retrieving content from the past that remains accessible in the present. Similarly, during tasks such as addition tests, line counting, or coordination tests, the concepts of fast and slow thinking, along with those mentioned earlier, can significantly influence performance. Transitioning from one stage of the test to another can be interpreted as moving between cognitive levels or as an active transformation, thereby impacting our understanding of cognitive processes and their development.

Research Objective

The main objective of the current study was to present the tools used in the Psychophysiological Variable Measurement Polypsychograph System for assessing psychomotor and cognitive efficiency, evaluate their psychometric properties, and examine their practical applicability. Through a detailed assessment of these methods, the study aims to provide a solid foundation for further research and contribute to the development and improvement of tools within the context of innovative computer technologies.

METHOD

Participants

The research was conducted on a sample of 1007 respondents from the Kuyavian-Pomeranian Voivodeship region who participated in preliminary and periodic studies in the field of occupational medicine and transport psychology. In the analyzed group, there were 907 males and 100 females in the age range of 18 to 74 years (*M* = 39.8, *SD* = 13), engaged in occupations requiring good psychomotor efficiency.

The study involved drivers and machine operators in motion, particularly forklift and crane operators, as well as individuals using private or company cars for professional purposes. The majority of participants had vocational or secondary education. The research was conducted within the realms of occupational medicine and transport psychology, as Polish law mandates psychological assessments for individuals working in roles demanding high psychophysical efficiency.

The second group consisted of 40 individuals who participated in the study using the test-retest method. These individuals, aged 18 to 26 years (*M* = 20.8, *SD* = 13), were amateur football or volleyball players representing the company in league competitions. Most of these individuals reported having secondary education.

Measures

The Psychophysiological Variable Measurement Polypsychograph System, as a device for psychophysiological diagnostics, obtained a certificate from the Polish Patent Office (No. P.418621) on April 16, 2019.

Methods for assessing psychomotor and cognitive efficiency were presented , encompassing the following stages of information processing: information reception, information processing, and response to information. These methods allow for the measurement of various aspects of psychomotor and cognitive efficiency, such as the efficiency of quick thinking (Addition Test), the ability to maintain attention concentration, perceptual field scanning (Number Localization Test), perceptual and visual attention efficiency (Line Test), simple rRT (Simple Coordination Test), and complex RT (Complex Coordination Test).

These tools take the form of computer applications, and the assessments are conducted in a seated position. The Psychophysiological Variable Measurement Polypsychograph System constitutes a set of methods enabling comprehensive management of a set of audio-visual tests using a programmable and interactive screen. It consists of a computer equipped with specialized software and an executive module that generates and receives test stimuli.

The design of the keyboard used in the system allows for reaction control through touch, movement, and sound, which is particularly important for individuals with manual limitations.

The study involved the use of five test matrices, which are an integral part of the Psychophysiological Variable Measurement Polypsychograph System.

The tests for simple and complex coordination have a time limit of 1 minute, whereas the other tests do not have such constraints. The duration of execution varies depending on individual participant capabilities, such as learning speed, attention, cognitive ability, and memory. On average, the line test and number test each take about 1 minute, while the addition tests are completed in approximately half a minute.

ADDITION TEST

The addition test utilizes a set of positive natural numbers from 0 to 9. This test does not require specific mathematical skills. The test involves adding a two-row sequence of numbers using a cursor that moves across successive numbers. To gather more data, two sets with different numbers were used. Performing this tet absorbs attention, requires focus, and involves simple logical operations. Key variables

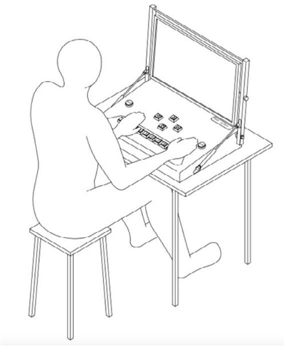

FIGURE 1.

The course of the examination with the Psychophysiological Variable Measurement Polypsychograph System. Source: GPE Psychotronics Archival Materials.

during this test include time, accuracy, and execution fluency, characterizing the pace and correctness of the participant's thinking.

NUMBER TEST

The number test consists of two boards divided into square fields, each containing a two-digit number. The test involves memorizing consecutive numbers from the first board and then locating them in the set of numbers on the second board. The participant uses keyboard buttons to move a frame to the field containing the memorized number. The program records the route the frame took to reach the intended location, the number of repetitions of the memorization process, the number of errors, and the execution time. This test relies on operational memory and perceptiveness.

LINE TEST

The line test is used as a method for measuring the efficiency of visual receptor function. This test assesses the "selectivity" of perception by focusing on the "detail" of the presented image. The test prese ts nine boards sequentially, differing in the number of thin black lines placed on a white background. The number of lines varies from 7 to 15. The participant's task is to count the lines and enter the result on the keyboard. Key variables in this test include the resolution and sharpness of the visual receptor and the focus of attention.

SIMPLE COORDINATION TEST

The simple coordination test is a modified version of a commonly used method by psychologists to study visuomotor coordination and the precision of movements. Successive digits appear on the exposure module screen, and the participant must react by pressing the keyboard button marked with the corresponding digit. The test is conducted in a forced mode, where the next digit appears only after the participant's correct reaction. In the validation process, one-minute sequences were used in the forced mode.

COMPLEX COORDINATION TEST

The complex coordination test is an extended method incorporating elements of thinking, used to measure psychomotor efficiency. The stimulus exposed involves simple mathematical tasks based on adding or subtracting single numbers. The participant's task is to enter the result using the keyboard. This test effectively illustrates the component of thinking time in psychomotor reactions.

TOOLS USED FOR VALIDITY ASSESSMENT

Raven's Standard Progressive Matrices Test. The test consists of a set of 60 matrices (incomplete patterns) featuring single or more complex figural arrangements (Jaworowska & Szustrowa, 2010). The participant's task is to complete each pattern by selecting the missing fragment according to logical principles. Matrix tests were used to verify the validity of the cognitive aspect of psychomotor efficiency in the Psychophysiological Variable Measurement Polypsychograph System.

Piórkowski-Type Reaction Meter. This device is used to assess visuomotor coordination and the precision of upper limb movements, while simultaneously measuring the temporal parameters of reactions (Korchut & Horoszkiewicz, 2018). It has been included in the indicators assessing psychomotor efficiency. The display panel of this device includes an upper row containing 10 points emitting light stimuli, and below it is an identical row of buttons of one color. The participant's task is to press the button under the illuminated point among the ten before it goes out. The illumination time is 0.5 seconds. In the forced mode, the possibility of emitting the next stimulus is available only after the correct reaction to the previous stimulus. The duration of the test was 60 seconds. In Figure 2, a graphical representation of a Piórkowski-Type Reaction meter with a control panel is shown.

Cross-Type Reaction Meter. This device allows for the measurement of psychomotor speed, spatial coordination, and the ability to think in the context of visual imagery (Korchut & Horoszkiewicz, 2018). Similar to the previous device, it consists of a control panel and a desk for the presentation and reception of stimuli. On the desk, there are four rows of diodes emitting light stimuli. In each row, two diodes are simultaneously illuminated: one in the vertical row and the other in the horizontal row. The participant's task is to quickly press the button located at the intersection of these two lines. The working mode and duration were identical to the Piórkowski-type apparatus. The graphic presentation of the Cross-Type Reaction Meter is shown in Figure 3.

Procedure

The study was conducted using the diagnostic tools mentioned above. Tests with the Psychophysiological Variable Measurement Polypsychograph System and the meters were performed individually.

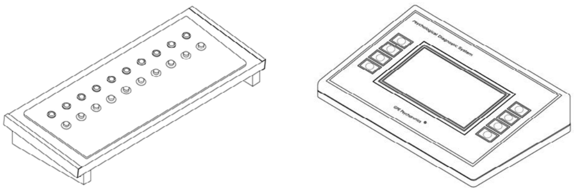

FIGURE 2.

Piórkowski-Type Reaction Meter with Control Panel. Source: GPE Psychotronics Archival Materials.

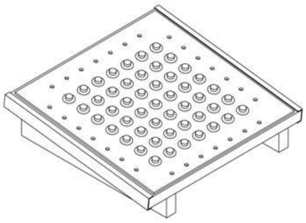

FIGURE 3.

Cross-Type Reaction Meter Graphic Representation. Source: GPE Psychotronics Archival Materials.

However, studies using scales and questionnaires were conducted in small groups (3-5 people) or individually.

A total of 1007 drivers and machine operators (Group 1) were examined, and the results obtained were utilized in the analysis of intercorrelations between individual tests. The study took place in a single psychological laboratory in Poland.

In the reliability test (Group 2), 40 participants aged 18 to 26 (mean age *M* = 20.8, standard deviation *SD* = 1.9) took part. The majority were males (*n* = 30). Inclusion criteria corresponded to the typical age range for participants in amateur football and volleyball leagues. Additionally, participants were individuals actively participating in company football or volleyball matches in the 12 months preceding the study.

The study was carried out on the company premises, where employees take part in corporate sports events. The choice of this environment aimed to reflect the real conditions in which participants most often engage in physical activity. Additionally, to avoid the influence of fatigue and stress on psychomotor test results, each participant had a 15-minute break before starting the tests. This short break was intended to allow participants to relax and achieve an optimal physical and mental state before starting the assessments.

Exclusion criteria included a negative interview regarding psychiatric disorders, cardiovascular system issues, and other illnesses that could affect psychomotor test results. Additionally, participants could not have a history of head injuries or other conditions directly affecting the study results, and they should be in good health without the presence of coexisting injuries affecting psychomotor abilities.

The correlation analysis between the Polypsychograph System and the Cross and Piórkowski type meters was conducted using the results of 300 individuals who completed all computerized tests and also underwent examinations with the RT meters.

Data Analysis

Statistical analyses were conducted using IBM SPSS Statistics 28 and Jamovi ver. 1.6.23. Using these tools, a comprehensive analysis of basic descriptive statistics was performed, accompanied by Shapiro-Wilk tests to assess normality. Pearson's correlation coefficient and intraclass correlation coefficient (ICC) were employed for the evaluation of reliability. The assessment of temporal stability involved the use of the paired *t* test for dependent samples. For the assessment of validity, in the absence of symmetric distribution in the analyzed variables, the Spearman's rho coefficient was utilized; otherwise, the Pearson's r coefficient was applied.

RESULTS

First, basic descriptive statistics were computed for the measured quantitative variables. Additionally, Shapiro-Wilk tests were conducted to check if the analyzed variables significantly deviated from a normal distribution. As indicated in Table 1, the distributions of the results of individual variables differed from a symmetric distribution. In the case of such deviations, the skewness values of these distributions were analyzed. If the skewness value fell within the range of -2 to +2, it was assumed that the distribution was not significantly asymmetric relative to the mean, allowing for the use of parametric tests (Mallery & George, 2010). It was noted that variables such as the mean RT in the second addition test and in the coordination test, as well as the number of correct responses in the second addition test and the line test exhibited skewness values exceeding this range. Reaction time was expressed in seconds.

In Table 2, basic statistics for the Raven's Standard Progressive Matrices test (TMS; for assessing nonverbal intelligence) and the Piórkowski and Cross-type RT meters are presented. For the meters, the average RT is shown in milliseconds, along with the number of correct reactions within a limited duration of 1 minute. The distributions of variables for the average RT on the Piórkowski type meter and the number of correct reactions on the Cross-type meter were found to be consistent with a Gaussian curve. The skewness value for all variables fell within the range of -2 to +2 (Mallery & George, 2010). Therefore, parametric tests were used in further analyses.

Reliability Assessment

Table 3 presents the values of Pearson correlation coefficients and ICC between successive measurements. The obtained values for both addition tests were the lowest among all analyzed variables (Rtt = 0.63-0.67). Nevertheless, these values allowed for the application of these methods in scientific research. Similarly, the results obtained in the tine test (Rtt = 0.71) should be considered acceptable.

Regarding the other methods, satisfactory results were observed, indicating measurement accuracy. Correlation results confirm the high reliability of the number test, as well as the simple and complex coordination tests, recommended for use in both scientific research and individual diagnosis (see Table 3).

Table 4 presents the mean results obtained in individual tests in the first and second assessments, along with the value of the difference statistic. Time units are presented in seconds, and the number of correct reactions (responses) in points. In the second addition test (TD2) and the line test (TLN), there were no statistically significant differences. The obtained results suggest that both methods exhibit relatively higher temporal stability than the others, indicating the participants' consistent performance levels in the measured abilities. The largest effect sizes of Cohen's d were observed in the average reaction time in the first addition test, in the number and line tests, as well as in relation to the number of correct reactions in the simple coordination test (see Table 4).

TABLE 1.

Descriptive Statistics for Variables Used in the Computer-Based Study Using the Polipsychograph System ($N = 1007$)

	AT in 1st Add Test	AT in 2nd Add Test	Correct in 2nd Add Test	AT in Num Test	AT in line test	Correct in Line Test	AT in Simple Coord Test	Correct responses in simple coord test	AT in Complex Coord Test	Correct responses in complex coord test
N	1007	1007	1007	1007	1007	1007	1007	1007	1007	1007
Mean	4.72	2.88	9.70	7.47	6.14	8.11	0.950	63.6	1.82	35.1
Median	4.45	2.59	10.0	6.53	5.84	9.00	0.920	64.0	1.67	35.0
Standard deviation	1.71	1.15	0.67	2.93	1.43	1.38	0.154	9.34	0.65	9.85
Minimum	1.80	1.30	4.00	2.81	3.74	0.00	0.640	31.0	0.88	8.00
Maximum	15.3	9.96	10.0	21.4	14.3	9.00	1.88	92.0	6.64	67.0
Skewness	1.54	2.17	-3.30	1.66	1.65	-2.22	1.29	-0.28	2.30	0.04
Kurtosis	4.38	7.78	16.2	3.36	4.23	6.29	2.82	-0.15	8.89	-0.23
Shapiro-Wilk *W*	0.90	0.83	0.50	0.86	0.88	0.69	0.92	0.99	0.82	0.99
Shapiro-Wilk *p*	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	< .001	.04

Note. AT in 1st Add Test = average time in the 1st addition test; AT in 2nd Add Test = average time in the 2nd addition test; Correct in 2nd Add Test = number of correct responses in the 2nd addition test; AT in Num Test = average time in the number test; AT in Line Test = average time in the line test; Correct in Line Test = number of correct responses in the line test; AT in Simple Coord Test = average time in the simple coordination test; Correct responses in simple coord test = number of correct responses in the simple coordination test; AT in Complex Coord Test = average time in the complex coordination test; Correct responses in complex coord test = number of correct responses in the complex coordination test.

TABLE 2.

Descriptive Statistics for the Raven's Standard Progressive Matrices Test and RT Meters in the Study ($n = 300$)

	TMS	AT in Piórkowski Meter	CR in Piórkowski Meter	AT in Cross-type Meter	CR in Cross-type Meter
N	300	300	300	300	300
Mean	47.3	523	114	1057	57.1
Median	48.0	519	115	1035	58.0
Standard deviation	6.30	39.2	10.1	143	7.45
Minimum	29.0	443	50.0	791	37.0
Maximum	58.0	645	134	1585	75.0
Skewness	-0.74	0.43	-1.96	0.75	-0.06
Kurtosis	0.16	-0.01	11.4	0.79	-0.35
Shapiro-Wilk *W*	0.95	0.98	0.88	0.97	0.99
Shapiro-Wilk *p*	< .001	.09	< .001	.003	.803

Note. TMS = Raven's Matrix test score; AT in Piórkowski Meter = average time in the Piórkowski meter; CR in Piórkowski Meter = correct responses in the Piórkowski meter; AT in Cross-type Meter = average time in the cross-type meter; CR in Cross-type Meter = correct responses in the cross-type meter.

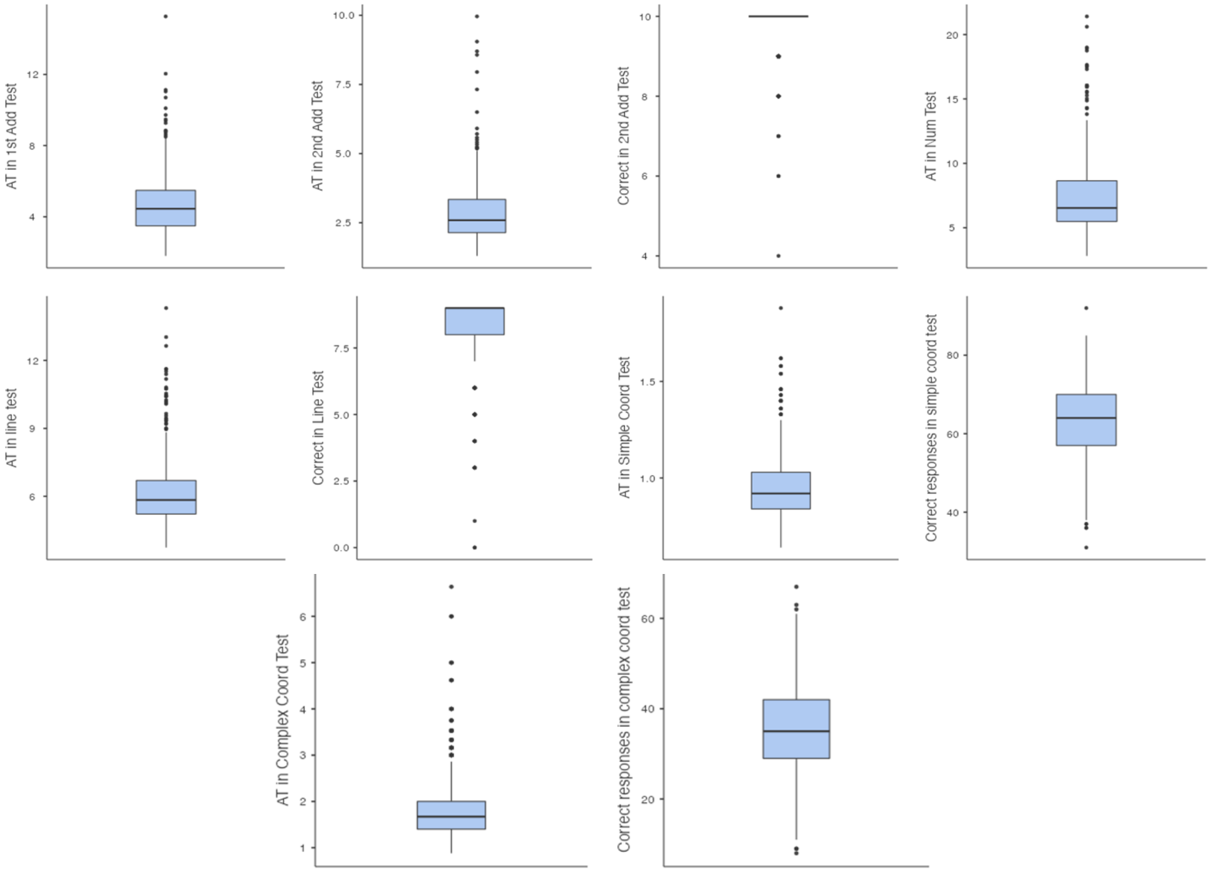

FIGURE 4.

The distributions of the outcomes of methods utilized in the computer-based Polipsychograph system (*N* = 1007).

TABLE 3.

Pearson's Correlation Coefficients and Intraclass Correlation Values (*N* = 40)

	TD1	TD2	TLB	TLN	TKP	TKP-R	TKZ	TKZ-R
ICC	0.59	0.60	0.83	0.66	0.72	0.92	0.84	0.84
95 CI (LL)	0.34	0.36	0.70	0.45	0.53	0.85	0.71	0.71
95 CI (UL)	0.76	0.77	0.90	0.81	0.85	0.96	0.91	0.91
Rtt	0.63	0.67	0.89	0.71	0.81	0.92	0.84	0.84
p	<.001	.255	<.001	<.001	.003	<.001	.028	.002

Note. ICC = intraclass correlation coefficient - a two-factor mixed effects model in which objects are random, and position effects are fixed; unitary measures are shown, the estimator is the same whether the interaction effect is present or absent; 95 CI (LL) = 95% confidence interval with lower limit; 95 CI (UL) = 95% confidence interval with upper limit; Rtt = Pearson's correlation value between repeated measurements; TD1 = Addition Test (exercise matrix) - average reaction time ; TD2 = Addition Test (task matrix) - average reaction time; TLB = Number Location Test- average reaction time; TLN = Line Test - average reaction time; TKP = Simple Coordination test - average reaction time; TKP-R = Simple Coordination test - number of correct reactions; TKZ = Complex Coordination test - average reaction time; TKZ-R = Complex Coordination test - number of correct reactions.

Validity Assessment

INTERSCALE CORRELATIONS

To estimate the validity of the tasks in the computerized the Psychophysiological Variable Measurement Polypsychograph System, the degree of correlation between individual test methods (variables) was examined, and correlations with other tests measuring analogous constructs were analyzed.

Table 5 presents the intercorrelations between individual variables. Variable names with the letter R indicate that the number of correct reactions was assessed, while the absence of this letter in the name suggests that the average reaction time was subjected to analysis. High

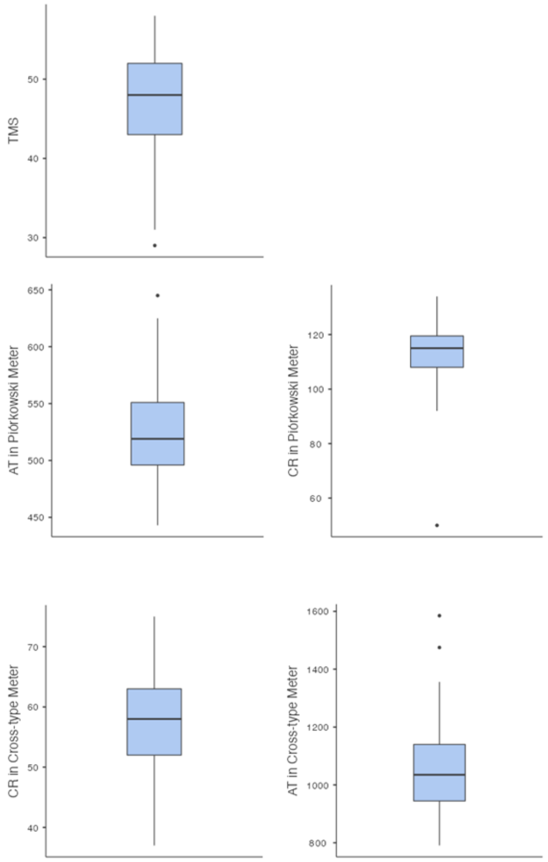

FIGURE 5.
The Distributions of Raven's Matrices Variables and Piórkowski and Cross-Type Reaction Meters (*n* = 300).

TABLE 4.
Temporal Stability of the Analyzed Variables (*N* = 40)

Variable	Study 1		Study 2		*t*	*d*
	M	*SD*	*M*	*SD*		
Average Reaction Time in Addition Test 1 (seconds)	4.33	1.38	3.08	0.96	7.34*	1.16
Average Reaction Time in Addition Test 2 (seconds)	2.82	0.77	2.66	1.22	1.15	0.18
Average Reaction Time in Number Test (seconds)	8.91	5.04	6.16	3.41	6.86*	1.08
Average Reaction Time in Line Test (seconds)	6.10	1.23	5.19	0.84	6.69*	1.06
Points in Line Test	8.72	0.64	8.65	1.03	0.72	-0.11
Average Reaction Time in Simple Coordination Test (seconds)	0.99	0.24	0.92	0.15	3.12*	0.49
Points in Simple Coordination Test (Reaction Time)	61.58	10.57	65.50	9.84	-6.01*	-0,95
Average Reaction Time in Complex Coordination Test (seconds)	1.78	0.44	1.68	0.46	2.29*	0.36
Points in Complex Coordination Test (Reaction Time)	34.38	7.66	36.88	9.05	-3.26*	-0.52

Note. **p* < .05

interdependencies were observed between average RTs (with the exception of the line test) of individual methods and the number of correct reactions in the test (with the exception of the line test). Negative correlations were also noted between average time and the number of correct reactions. Cognitive aspects and motor aspects were strongly correlated in both test tasks and methods.

CONVERGENT VALIDITY – CORRELATIONS WITH OTHER MEASURES

Cognitive Aspect. Table 6 presents Pearson correlation coefficients between the TMS and other variables belonging to the Psychophysiological Variable Measurement Polypsychograph System. Significant statistical interdependencies were demonstrated (ranging from -0.61 to -0.44). The TMS results negatively correlated with the average RT in both addition tests and the number test.

TABLE 5.

Intercorrelations of Scales in the Normative Sample (*N* = 1007)

		TD1	TD2	TLB	TLN	TLN-R	TKP	TKP-R	TKZ	TKZ-R
TD1	ρ	—								
	p	—								
TD2	ρ	0.62	—							
	p	< .001	—							
TLB	ρ	0.63	0.67	—						
	p	< .001	< .001	—						
TLN	ρ	0.25	0.34	0.23	—					
	p	< .001	< .001	< .001	—					
TLN–R	ρ	−0.07	−0.09	−0.02	−0.20	—				
	p	.26	.116	.705	< .001	—				
TKP	ρ	0.54	0.67	0.71	0.32	−0.10	—			
	p	< .001	< .001	< .001	< .001	.099	—			
TKP–R	ρ	−0.54	−0.67	−0.71	−0.32	0.10	−0.99	—		
	p	< .001	<.001	< .001	< .001	.095	<.001	—		
TKZ	ρ	0.54	0.74	0.59	0.33	−0.10	0.63	−0.63	—	
	p	< .001	< .001	< .001	< .001	.07	< .001	< .001	—	
TKZ–R	ρ	−0.54	−0.749	−0.59	−0.33	0.10	−0.63	0.63	−0.99	—
	p	< .001	< .001	< .001	< .001	.079	< .001	< .001	< .001	—

Note. TD1 = Addition Test (exercise matrix) - average reaction time; TD2 = Addition Test (task matrix) - average reaction time; TLB = Number Location Test - average reaction time; TLN = Line Test - average reaction time; TLN-R = number of correct responses; TKP = Simple Coordination Test - average reaction time; TKP-R = Simple Coordination Test - number of correct reactions; TKZ = Complex Coordination Test - average reaction time; TKZ-R = Complex Coordination Test - number of correct reactions.

TABLE 6.

Correlation Analysis of Raven's Progressive Matrices with SDP Variables (*N* = 300)

	TMS	TD1	TD2	TLB
TMS	—			
TD1	−0.49	—		
TD2	−0.61	0.60	—	
TLB	−0.44	0.60	0.67	—

Note. TMS = Raven matrix Test Score (as the number of points); TD1 = Addition Test (exercise matrix) - average reaction time; TD2 = Addition Test (task matrix) - average reaction time; TLB = Number Location Test - average reaction time; $p < .001$

Motor Aspect. In Table 7, Pearson correlation coefficients are presented for the Piórkowski and cross meters and tests for assessing simple and complex coordination. Positive and statistically significant dependencies were obtained. The correlation coefficient of the average RT in the complex coordination test in relation to the same parameter on the Piórkowski meter was statistically significant and positive ($r = 0.48$, $p < .001$), while the remaining parameters were very strong (from 0.62 to 0.74).

DISCUSSION

The current study presented a battery of tests to assess psychomotor and cognitive performance in the Psychophysiological Variable Measurement Polypsychograph System. Results were analyzed using the ICC and Pearson correlation values between repeated measurements (Rtt). ICC values for the attention test (number test) and tests of simple and complex coordination (in terms of time and number of correct reactions) were high, indicating high reliability. These results suggest that the presented methods are stable over time and can be applied in both scientific research and individual diagnosis. However, ICC values for addition tests and the line test were less accurate, suggesting lower measurement precision, and improvements might be needed in these tests.

It is worth noting that in the first addition test, participants were introduced to a cycle of exercises where they were supposed to familiarize themselves with the instructions displayed on the screen and follow them accordingly. Although the initial matrix may seem very easy, as it involves entering addition results such as 2 + 2, their execution provides significant information about adaptation to the task and learning speed. Participants' reactions, such as errors in execution, skipping instruction steps, or the need for additional support, allow for the assessment of adaptation pace, information processing, thinking, and adherence to established rules.

In the second test, when participants already had experience from the first attempt, they performed the task much faster, indicating acquired knowledge and adaptive skills. This faster reaction can be interpreted in the context of Brown's microgenesis theory as a clear development of cognitive processes through gradual movement between different levels, similar to how participants develop their skills in subsequent tests based on previous experiences. Each subsequent test is a stage in the evolution of participants' skills, similar to stages of development according to Brown. Although it may seem like a purely cognitive task, it also requires some psychomotor skills, especially if

TABLE 7.

Correlation Analysis of Piórkowski and Cross Meters With SDP Variables ($N = 300$)

	Piórkowski-Type	Cross-Type	TKP	TKZ
Piórkowski-Type	—			
Cross-Type	0.71	—		
TKP	0.74	0.71	—	
TKZ	0.48	0.62	0.68	—

Note. TKP = Simple Coordination Test - average reaction time; TKZ = Complex Coordination Test - average reaction time.

$p < .001$

participants need to enter results on a computer or paper within a limited time. The process of processing mathematical information and performing actions requires motor coordination, especially if the task is to be performed quickly and accurately.

Furthermore, it's intriguing to examine these obtained results in these tests in the context of Kahneman's (2017) concept, which analyzes cognitive processes (fast and slow thinking) and decision-making in terms of adaptation to various situations and conditions. We can hypothesize that participants who performed better in the second test may demonstrate enhanced ability to adapt to changing task conditions, thus affirming the thinking concept, which also highlights the role of adaptation in the cognitive process. Combining Brown's (1989) theory with Kahneman's (2017) allows for a deeper understanding of the dynamic nature of cognitive and adaptive processes within the framework of these methods.

Validity was assessed by analyzing correlations between the TMS and other variables in the Psychophysiological Variable Measurement Polypsychograph System. Negative correlations were found between TMS scores and RTs in addition tests and the number test. Individuals with higher TMS scores exhibited shorter reaction times in tasks presented by the computerized SDP module. The results suggest convergent validity for the cognitive aspect.

The correlation results between both addition tests and TMS, as well as the number test, aligned with expectations. Individuals with higher levels of nonverbal intelligence may be more efficient in analyzing and understanding stimuli, leading to faster RTs in addition tasks. It is worth noting that the strength of this relationship increased from 24% in the first trial to 37% in the second, suggesting growing consistency between intelligence level and RT as the task progresses. The associations of the number test with TMS showed 19% variability in results. It's important to remember that TMS assesses nonverbal intelligence by analyzing the ability to solve abstract problems and identify patterns, while the number test mainly involves concentration and working memory. Individuals may vary in these skills, leading to diverse outcomes.

Criterion validity for the motor aspect was assessed by correlating reaction meters (Piórkowski and cross test) with computerized tests for simple and complex coordination. Positive and statistically significant relationships were found, indicating convergent validity for the motor aspect.

All correlation values turned out to be statistically significant and generally strong. Only the correlation between the average RT in the complex coordination test and the average time obtained on the Piórkowski meter was positively moderate. This also speaks well to the validity of this method. On the Piórkowski meter, only the appearance of a stimulus (lights) on the dashboard is tracked, and a reaction of clicking the button located under that light quickly follows. In the case of the complex coordination test, participants not only have to react to the appearing stimulus on the screen (performing addition or subtraction on single numbers), but also use called fast thinking (Kahnemann, 2017) to input the correct result using the appropriate keys on the keyboard.In conclusion, the current study provides evidence for the reliability and validity of the Psychophysiological Variable Measurement Polypsychograph System in assessing both cognitive and motor aspects. However, improvements may be considered for specific tests showing lower reliability. The findings contribute to the understanding of the psychophysiological diagnostic system and its applicability in research and individual assessments.

Limitations

The study was conducted on a sample of respondents from one region in Poland. This may limit the overall representativeness of the results. Future research should consider broader population groups and various occupational categories to assess how individual methods perform in different research contexts.

The focus of the study was on assessing the reliability and validity of selected methods used in the Psychophysiological Variable Measurement Polypsychograph System.

No comparisons were made with other computerized tools available on the market, which could provide additional insights into the uniqueness and effectiveness of these methods or their limitations.

There are significant limitations in the tools themselves. The level of difficulty of the addition tests is relatively low, which makes them unable to precisely distinguish between the tested groups in terms of the number of errors made. To obtain more discriminating results, it would be advisable to introduce more advanced matrices with a greater number of tasks in the addition tests. Extending the duration of the study, for example, to 3 minutes, could also reveal additional significant information, such as the reaction to fatigue or resistance to effort.

In the case of the research sample, it is crucial for it to be representative. The results of many other studies, such as those conducted by Uchroński (2020) or Horoszkiewicz and Horoszkiewicz (2022), and Horoszkiewicz et al. (2022) suggest that the described methods can be effectively applied in various areas. Therefore, it is worth ensuring appropriate differential analysis between different clinical groups and the control group, taking into account differences related to education level, age, and gender. This analysis would allow for a better understanding of the impact of these factors on psychomotor test results and their potential application in different contexts.

Future research should aim to refine the Psychophysiological Variable Measurement Polypsychograph System, improving its functionality, and adapting it to different age groups. Collaboration with various institutions, transport companies, or sports organizations could help develop practical applications of this system in various fields.

Conclusions

The presented methods of the Psychophysiological Variable Measurement Polypsychograph System toolkit exhibit good psychometric properties in terms of reliability and validity. Results of the analysis suggest that most tests are correlated with each other, indicating consistency in measurements. Furthermore, the chosen methods are deemed valid, both in cognitive and motor aspects. The findings highlight the utility of these methods in measuring various cognitive and motor skills. However, the ultimate assessment should depend on the specific research context and study objectives.

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DATA AVAILABILITY

The data will be made available upon reasonable request to the corresponding author.

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