# Adolescents' Cognitive Abilities, Reaction Time, and Working Memory Performance by Vienna Test Systems

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**Abstract—**Mental and physical health components are critical in child's development. However, adolescents are especially vulnerable group presenting multiple health risks of chronic disease, sleeping and eating problems. Moreover, the long time spent at screens increases possibility to develop addictions. There is a lack of comprehensive interdisciplinary assessment tools for adolescents, to assess their mental health components, and provide preventive activities. It is very important to develop a methodology that can accurately assess the minor cognitive and health deviations that can be caused by an unhealthy lifestyle and excessive time spent on screens. This research explores the possibilities to record and compare parameters of cognitive abilities, reaction time, and working memory using Vienna test systems for different groups of adolescents by their physical activity and health levels. The results of this study demonstrated that the reaction time in adolescents was shorter using the leading hand in comparison with using the non-leading hand, 272.842 ± 44.001ms vs 306.631 ± 57.081ms on Vienna test for low physical activity (LPA) adolescents group. In the STROOP test color evaluation results were faster than word reading test results. The median of reaction time of LPA adolescents for color evaluation was 0.897 ± 0.221ms and 0.968 ± 0.15ms for reading. Vienna test system has specific tests that can be used to determine memory parameters, providing different assessment approaches to compare the obtained results. Group of adolescents with mild chronic health conditions performs statistically significantly lower parameter in particular tests in comparison with adolescents with low and high physical activity.

**Keywords—**adolescents, cognitive abilities, reaction time, working memory, Vienna test system

## 1 Introduction

Mental and physical health components are critical in every child's development period, but adolescents are especially vulnerable group, which has health risks of chronic disease, complications during acute illness periods associated with increased anxiety, sleeping and eating problems, possibility to develop addictions. Adolescent health needs special attention from researchers and decision-makers to ensure an acceptable level of health for future generations [1]. One of the most characteristic problems of adolescents is the long time spent at screens, which can lead to computer addiction and health complaints. Problematic internet use is a contributing factor to many health complaints (somatic and psychological complaints) because it can replace daily physical activity, increase unhealthy eating habits and cause sleeping problems [2]. Increased screen time is associated with less physical activity, being overweight, skipping school, alcohol use and unhealthy eating habits, bullying and being bullied and several other psychosocial problems [3]. The amount of screen time has a significant impact on the health of adolescents. Positive associations were observed between screen-time and sleeping problems, musculoskeletal pain, and depression of adolescents' girls [4]. Proportions of studies reporting positive relationships with screen time were relatively lower in adiposity (50.6%) and higher in myopia (59.2%) and psycho-behavioral problems (81.8%) [5].

There is a lack of comprehensive interdisciplinary assessment tools for school age children, particularly adolescents, to assess their physical and mental health components, and provide preventive activities. It is very important to develop a methodology that can accurately assess the minor cognitive and health deviations that can be caused by an unhealthy lifestyle, time spent on screens and addiction. To solve this problem, it is necessary to find out the relationships between different parameters of adolescent psychophysiological indicators.

One of the tasks of pedagogues is to develop appropriate teaching methods for children with health or cognitive disabilities. Working memory training is a good way to help children with attention problems and hyperactivity in the classroom. Children who have higher-quality learning opportunities experience fewer difficulties in their academic life [6]. The relationship between working memory, mathematical ability and cognitive impairment in children with specific learning disabilities in mathematics strongly correlates. Insufficient spatial working memory can impede the formation of mental number lines, information storage, and arithmetic fact retrieval [7]. By developing certain cognitive abilities, it is easier for children and adolescents to overcome their inherent difficulties.

It was found that attention and working memory are closely connected with intelligence of the person. Information processing forms the cognitive basis of intelligence. Relatedness of attention and working memory as predictors of intelligence were examined in the research. Models of advanced progressive matrices (APM) and Zahlen-Verbindungs-Test (ZVT) were used as a criterion variable. When APM represented intelligence, the final model suggested both working memory and attention as significant predictors that correlate with it. In contrast, when ZVT represented intelligence, the model included only attention as significant predictor. The limitation of the models to working memory as single predictor led to an insufficient result [8].

Another indicator that relates to intelligence is reaction time. People who perform well in intelligence tests also tend to have faster and less variable response times. Faster information processing can lead to a higher intelligence [9].

Results indicate that such performance aspects, as speed and accuracy, are distinct in the shape of growth and in the prediction of growth curve parameters by intelligence. The study investigates the effects of intelligence, perceptual speed, and age on intraindividual growth in attentional speed and attentional accuracy. It was found that for attentional speed, intelligence significantly predicted baseline performance, but not performance growth. Perceptual speed influenced both baseline performance and performance growth [10]. It was also found that the ability to learn abstract rules and the efficiency of retrieving information from long-term memory together with working memory are important components underlying intelligence [11].

Cognitive skills, especially in terms of education, are correlated with the effort of individual exerts and they are combination in theoretical (levels of knowledge and its hierarchical organization) and functional (operational and physical limitations of perceptions) cognitive abilities that connected with self-learning, self-development, self-treatment and self-knowledge abilities and possibility to perform adaption of information, main idea recognition and selection, and memorization not only for a new amount of information but also possibilities to integrate new level of self-knowledge [12]

Computer tests are widely used in the assessment of cognitive skills of people and in the analysis of correlations between them. Significant correlations between cognitive abilities such as response time to individual stimuli to simultaneous or sequential stimulus combinations, reactive stress tolerance, attention, and response rate in situations requiring rapid response to various parameters and other cognitive parameters of sportsmen were observed using Reaction Time Test (RT) and the Determination Test (DT) taken from the Vienna Test System (VTS) [13]. Investigation using DT from VTS allowed to conclude that there is a correlation between number of hours of physical activity per week and the level of behavioral response to stress of students [14].

This study explores relationships between cognitive abilities (general intelligence, concentration, stress tolerance, short and long-time memory, reaction time) of adolescents with different amount of time spent in physical activity and problematic internet use and chronic health condition using Vienna test system (VTS).

## 2 Methodology

### 2.1 Sample selection

Data for this study were drawn from the national longitudinal research project on adolescents' problematic internet use. The study was approved by the Health Care Ethics Review Committee at the Latvian Academy of Sport Education (Latvia) and has been developed in line with the Declaration of Helsinki (World Medical Association). In this research three groups of adolescents where selected, (1) adolescents with high physical activity (HPA) (8 males, 11 females; mean ± SD ages 13.11 ± 2.47), (2) adolescents with low physical activity (LPA) (7 males, 15 females; mean ± SD ages 13.05 ± 1.05), and (3) adolescents with mild chronic health conditions (CHC) (15 males, 4 females; mean ± SD ages 13.58 ± 1.35). Participants represented the 3 different regional districts of Latvia and were involved in middle and secondary general education schools and special schools for adolescences with CHC.

### 2.2 Variables and measures

Modern psychometric used reliable and valid measurement tools in the field of intelligence research. Many of developed tests are based on CHC (Cattell-Horn-Carroll) model. This model from psychological theory is developed on the structure of human cognitive abilities [15]. In CHC theory of the general intelligence contains multidimensional hierarchical skills (factors) structure and some of these skills have a broader scope than others according to specific information processing domains (sensory, motor, memory). These skills may be measured directly using a specific task or test. CHC hierarchical models contains broad skills (abilities) are clusters of narrow skills that are mutually more correlated with each inside specific cluster than with other in the different clusters.

The goal that researchers and teachers try to achieve is to illuminate possible weakness in cognitive performance in children in healthy population, but that is more important in groups with different mental disorders like Developmental Dyscalculia (DD) disorders. DD have relationships with attention and working memory mechanisms have that have manifestation in the performance of mathematical skills. Targeting children population with DD, problems are encountered in serial memory, memorization and executing algorithms. Computerized cognitive tests allows to understand how brain responds to different stimulus materials, and separate factors that have an influence on learning ability of the mathematics and other related skills. One of the factors that can be studied using computerized tests is attention that plays important role, due to connectivity between attentional disorders and performance in numerical processes [7].

The Vienna Tests system (VTS) contains wild spectrum of cognitive tests that fits with Cattell-Horn-Carroll model (CHC) and represents different aspects of cognitive abilities and general Intelligence [16]. These tests represent different types of knowledge – reaction and decisions speed, information processing, working memory (short- and long-term) capacity, reasoning ability. In different tests speed of reaction and numbers of errors are used as markers of the test processing quality [17]. Six subtests of the VTS were used for this research – Adaptive Matrices test (AMT), Cognitron (COG), Determination test (DT), Figural Memory test (FGT), Stroop test (STROOP) and Reaction time test (RT). These tests were used to assess general intelligence, concentration, stress tolerance, memory, cognition interference (automated vs controlled information processing) and reaction time (see Table 1) with short description of the used tests. Usually, tests were performed with leading hand, except where participants work with both hands and simple RT6 test where tests were performed twice using both hands – right and left.

**Table 1.** Vienna tests hierarchy according CHC model

| **Memory Loading** |
|---|
| Figural Memory Test (FGT) – working (short- long-) memory |
| **Simple Motor Reactions** |
| Reaction Time S6 (RT6) tests – reaction to single stimulus (reaction speed) |
| Reaction Time S1 (RT) tests – reaction to single stimulus (measure reaction and motor speed) |
| **Cognitive Ability** |
| STROOP Test – specific interference condition (word/colour) |
| Cognitrone test (COG) – concentration, cognition |
| Adaptive Matrices Test (AMT) – general intelligence |
| Determination Test (DT) – stress tolerance |

### 2.3 Statistical analyses

Research data were obtained using VTS tests, then data processed using MathWorks Matlab 2020a semi-automatized scripts and statistical analyses were performed using IBM SPSS Version 28. Data analyses included descriptive statistics calculating means and standard deviations for groups descriptions, parametrical ANOVA and non-parametrical Kruskal-Wallis test and correlations test for comparing observed cognitive tests results with statistical significance levels of $P < 0.05$ for these analyses. Beside standard Vienna Tests output values additional variables has calculated and used for analysis.

## 3 Results

Summary of main parameters of the VTS cognitive tests results are represented in the Table 2. In general, the results of adolescents with mild chronic health conditions (CHC) were significantly different from two other groups, while no significant differences were observed between group of adolescents with high physical activity (HPA) and group of adolescents with low physical activity level (LPA). Adolescents of HPA group and LPA group showed better results in many Vienna test parameters (general intelligence, concentration to work, reaction speed etc.) in comparison with CHC group adolescents. Surprisingly that in case of memory recall error values (FGT) no significant differences between all groups were observed. In some cases, adolescents from LPA group just did not try to recall figures after first pause of 5 minutes.

**Table 2.** Summary of VTS – AMT, COG, FGT tests results across experimental groups (ANOVA with Tukey Post Hoc)

| | AMT | AMT | COG | COG | COG | COG | FGT | FGT | FGT | FGT |
|---|---|---|---|---|---|---|---|---|---|---|
| Groups | General Intelligence | Correctly Worked Items | Mean Time "Correct Reactions" (sec) | Sum "Correct Reactions" | Mean Time "Incorrect Reactions" (sec) | Sum "Incorrect Reactions" | Reproduction I | Reproduction II | Errors Reproduction I | Errors Reproduction II |
| HPA | −1.89 ± 0.86 | 8.64 ± 2.13 | 1.94 ± 0.34 | 53.5 ± 4.35 | 1.83 ± 0.6** | 6.5 ± 4.35 | 7.59 ± 1.5 | 7.59 ± 2.19 | 1.04 ± 2.03 | 0.77 ± 1.02 |
| LPA | −1.87 ± 0.89 | 8.74 ± 2.4 | 2.04 ± 0.43 | 54.52 ± 2.38 | 2.18 ± 0.72** | 5.47 ± 2.38 | 8.1 ± 1.04 | 7.84 ± 1.11 | 2.84 ± 8.08 | 1.73 ± 2.46 |
| CHC | −2.94 ± 1.19* | 5.95 ± 2.99* | 2.53 ± 1.23* | 49.05 ± 7.99* | 2.65 ± 1.36** | 10.94 ± 7.99* | 4.5 ± 3.07* | 5.25 ± 2.62* | 1.88 ± 2.02 | 2.25 ± 2.69 |

*Notes:* * Group with CHC different from other groups at $p < 0.05$ level. ** Groups are different at $p < 0.05$ level.

STROOP tests data showed that reading the name of the colors were slower and significantly different between all groups in comparison with the naming of the colors where differences between results were not statistically significant. Medians of reaction time were also different between all groups as well in case of reading incongruent colors, but no differences in the part of naming the color of the word were observed. Again, results of missed words and reaction time for the reading names of the colors group with CHC performed significantly different in comparison with other two groups (LPA and HPA) (see Table 3). The median of the reaction time reading the colors were slower than naming the colors test parts. Results in all combinations of reactions time in the case of the congruent or incongruent stimulus conditions had the same tendency.

**Table 3.** Summary of VTS – STROOP test results across experimental groups (ANOVA with Tukey Post Hoc)

| | STROOP | STROOP | STROOP | STROOP | STROOP | STROOP | STROOP | STROOP | STROOP | STROOP |
|---|---|---|---|---|---|---|---|---|---|---|
| **Groups** | **Median for Reaction Times – Reading (sec)** | **Median for Reaction Times – Reading Congr** | **Median for Reaction Times – Reading Incongr** | **Sum of Incorrect Reactions – Reading** | **Median for Reaction Times – Naming (sec)** | **Median for Reaction Times – Naming Congr** | **Median for Reaction Times – Naming Incongr** | **Sum of Incorrect Reactions – Naming** | **Reading Interference Tendency (sec)** | **Naming Interference Tendency (sec)** |
| HPA | 1.046 ± 0.253** | 0.981 ± 0.22 | 1.074 ± 0.273** | 6.22 ± 7.57 | 0.891 ± 0.233 | 0.831 ± 0.215 | 0.914 ± 0.234 | 4.59 ± 3.3 | 0.093 ± 0.101 | 0.083 ± 0.057 |
| LPA | 0.968 ± 0.15** | 0.903 ± 0.135 | 0.99 ± 0.158** | 3.1 ± 2.9 | 0.897 ± 0.221 | 0.832 ± 0.175 | 0.926 ± 0.25 | 3.52 ± 3.18 | 0.087 ± 0.076 | 0.094 ± 0.114 |
| CHC | 1.167 ± 0.331** | 1.118 ± 0.425 | 1.262 ± 0.439** | 22.83 ± 32.18* | 0.967 ± 0.167 | 0.929 ± 0.125 | 0.993 ± 0.185 | 8.72 ± 10.19* | 0.143 ± 0.215 | 0.063 ± 0.092 |

*Notes:* * Group with CHC different from other groups at $p < 0.05$ level. ** Groups are different at $p < 0.05$ level.

In motor reaction (RT) and DT tests groups with CHC performed significantly different (slower) results than other groups. However, a LPA group showed better performance in case of reaction time and stress resistance. That possible may be explained by their dependency of the screen time (gaming mostly) but these differences were not statistically significant (see Table 4, where RT61 parameters – for leading hand and RT62 parameters for non-leading hand).

**Table 4.** Summary of VTS – RT and DT tests results across experimental groups (ANOVA with Tukey Post Hoc)

| | RT | RT | RT | RT | RT61 | RT61 | RT62 | RT62 | DT | DT | DT | DT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Groups | Reaction Speed | Dispersion of Reaction Speed | Motor Speed | Dispersion of Motor Speed | Reaction Speed | Dispersion of Reaction Speed | Reaction Speed | Dispersion of Reaction Speed | Number of Stimuli | Correct | Incorrect | Median Reaction Time |
| HPA | 302.63 ± 41.87 | 38.86 ± 13.53 | 192.45 ± 69.85 | 34.31 ± 14.97 | 288.727 ± 66.522 | 45.409 ± 22.948 | 321.454 ± 82.52 | 51.636 ± 18.172 | 244.95 ± 18.26 | 217.72 ± 21.26 | 26.45 ± 24.73 | 0.81 ± 0.05 |
| LPA | 284.05 ± 38.97 | 37.78 ± 22.19 | 184.57 ± 68.44 | 33.63 ± 13.61 | 272.842 ± 44.001 | 40.631 ± 12.811 | 306.631 ± 57.081 | 48.21 ± 16.477 | 251.21 ± 38.2 | 228.73 ± 37.04 | 22.94 ± 17.62 | 0.82 ± 0.12 |
| CHC | 332.66 ± 33.3* | 54.61 ± 17.66* | 241.61 ± 94.15 | 48.16 ± 27.37 | 358.578 ± 187.026 | 72.631 ± 52.494* | 408.894 ± 187.805* | 105.526 ± 53.23* | 199.1 ± 41.22* | 171 ± 46.03* | 28.73 ± 17.77 | 0.94 ± 0.1* |

*Note:* * Group with CHC different from other groups at $p < 0.05$ level.

Additional variables (coefficients) were calculated for COG, STROOP and DT tests. For determination test two variables were calculated. The idea behind this is to reduce number of variables used for data analysis. First of these variables was *STIMDT* which shows ratio between total number of stimuli presented (*ST*) to participants versus total number of given reaction (*RE*). This coefficient shows performance of responses in this test.

$$STIMDT = ST/RE \tag{1}$$

Second variable was *PERFDT* that show quality of responses and it was calculated as ratio between correct answers (*CA*) – divided by sum of all incorrect answers (*DE* – delayed, *IN* – incorrect, *OM* – omitted)

$$PERFDT = CA/(DE + IN + OM) \tag{2}$$

The results of the Cognitron test could be described by following calculated variables, *PERFCOG* as ratio of correct answers (*CA*) divided by incorrect answers (*IA*). Second variable was *RTCOG* that shows time ratio between correct reaction time (*CT*) and incorrect reaction time (*IT*).

$$PERFCOG = CA/IA \tag{3}$$

$$RTCOG = CT/IT \tag{4}$$

The results of the Stroop test could be described by two calculated variables, *PERFSTR* as ratio of incorrect reactions of reading colors (*RC*) divided by incorrect reaction of naming colors (*NC*). Second variable was *RTSTR* that shows time ratio of the median for reaction times reading (*RR*) divided by the median for reaction times of naming (*RN*).

$$PERFSTR = RC/NC \tag{5}$$

$$RTSTR = RR/RN \tag{6}$$

Statistically significant differences were observed in *PERFDT* variable. These results showed that the performance of the group with CHC was lower in comparison with other groups but these differences were not statistically significant (see Table 5).

**Table 5.** Groups differences in test performance by the calculated values

| Groups | STREDT | RESQUDT | PERFCOG | RTCOG | PERFSTR | RTSTR |
|---|---|---|---|---|---|---|
| HPA | 1.004 ± 0.056 | 2.309 ± 0.283 | 12.623 ± 7.15 | 0.981 ± 0.222 | 0.818 ± 0.637 | 1.107 ± 0.155 |
| LPA | 1.015 ± 0.084 | 2.282 ± 0.431 | 13.527 ± 12.687 | 1.021 ± 0.281 | 1.524 ± 1.578 | 1.193 ± 0.216 |
| CHC | 1.016 ± 0.117 | 1.941 ± 0.5* | 8.058 ± 6.952 | 1.187 ± 0.445 | 2.965 ± 4.547 | 1.229 ± 0.387 |

*Note:* * Group with CHC different from other groups at $p < 0.05$ level.

## 4 Discussion

The results of reaction time of the three groups of adolescents were different. The reaction time of the CHC group was slower than the reaction time of the two other groups, especially with non – leading hand. It was found that people with higher intelligence level also tend to have faster and less variable reaction times [9]. Thus, the results obtained in the study confirm this regularity.

Psychometrical tests used for measure of the problem-solving task like a Tower of Hanoi task (TOH) demonstrate a strong relationship between the result of the test and the obtained grades in programming course as stated in research [18]. During programming course where the problem-solving skills were improved, moreover, the TOH test results also significantly improved in the test group in comparison with the control group. These studies show that the cognitive tests results may show a prediction about the effectiveness of education and these methods may be used for forecasting the expected success of students. Also, in our study we found strong relation between grades in the intellectual subtests AMT, COG, FGT and STROOP and groups of adolescents, these differences are smaller when motor skill tests were performed in RT and DT subtests.

Research have shown that higher IQ in adolescence prospectively predicts a younger subjective age in later life, and higher openness explains part of this correlation [19].

Results of our research have shown that CHC group has lower general intelligence level than adolescents with high and with low physical activity. These results suggest that it is necessary to develop and use the best methods for promoting the development of intelligence and other psychophysiological parameters of students from CHC group.

Additional variables (coefficients) allow make test performance and results comparison using various statistical methods (such as regression correlation, etc.) between the Vienna tests and also in combinations with other observation methods (EEG, other questionnaires). These variables show general test performance because they show ratio between correct and incorrect responses or time ratio between these events. These results show groups different performance across COG, STROOP and DT tests, and this confirms the observation results obtained directly from the test data.

Intellectual tasks tests like AMT, COG and working memory tests like FGT and Automated Working Memory Assessment (AWMA) have successfully used for testing working memory and attention in schools and using sort forms of these tests also in pre-schools, this allows make early diagnosis of ADHD and others mental disorders as well. This allows to correct and enhance learning skills of kindergarten children and schools' adolescents who face working memory and attention difficulties in cooperation with psychologist and teachers [6].

Cognitive and metacognitive skills develop gradually depending on individual effort and teaching methods. Metacognitive skills promote the proper functioning of the cognitive and psychophysiological mechanisms and intelligence development. Metacognitive skills are critically crucial for self-learning and self-development [12]. So teaching methods for the development of metacognitive skills are important for all children including especially children with chronic diseases. One of the most important tasks of education is to teach students to adapt to new situations, find ways to explore possible solutions and solve problems [18]. Therefore, educators should develop approaches and methods that could help to achieve these goals.

## 5 Author note

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