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RECORDING ADOLESCENT'S PHYSICAL ACTIVITY USING TRACKING DEVICES AND OBSERVATION OF COGNITIVE ABILITIES

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ABSTRACT

Physical activity is vital important for the holistic development of adolescents, fostering their physical, cognitive, and social health. Measuring daily physical activity is necessary for objective monitoring of the necessary amount of physical activity to maintain health. Various physical activity trackers have been developed to increase an individual's awareness of physical activity throughout the day, but it is important to choose one that precisely measures the performance of various exercises and is easy to use. The aim of the study was to develop methodology and protocols for tracking adolescent's daily physical activities, sleep duration and quality, and assess dynamic of adolescent's motor skills and psychophysiological parameters. A case study to evaluate the correlation of physical and cognitive parameters with screen time dependency in adolescents was carried out. Two adolescent's groups were organized: group with partly supervised physical exercise program and group with fully supervised physical exercise program. The level of physical activities was recorded with Fitbit and Actigraph fitness trackers and mobile applications. Adolescent's motor skills were assessed by using the Bruininks – Oseretsky Bot-2 method, and psychophysiological parameters were assessed using Vienna tests before and after starting complex of physical activities. The results of the research suggested that the developed methodology gave ability to record adolescent's physical and behavioural activity during the 16-weeks physical exercise program and compare it with their self-reported physical activities. Fitbit fitness trackers are more preferable in comparison with Actigraph because it is easier to use it in partly supervised activity conditions, and it is possible to register sleep duration and heart rate changes with Fitbit. Using the developed methodology, and taking into account changes in physical activities, it is possible to assess the dynamic of physical and psychophysiological parameter changes of adolescents.

Keywords: *physical activity, adolescents, tracking devices, physical abilities, cognitive abilities*

Introduction

Physical activity is one of the key prerequisites for a healthy lifestyle, in children and adolescents. It is vital important to the holistic development of young people, fostering their physical, cognitive, and social health. Regular physical activities adapted to the child's individual needs, abilities, health, gender and age have a positive effect on the child's cognitive and physical growth and maturation. Childhood physical activity contributes to better health and well-being in adulthood (Kostecka et al., 2017). Physical activity plays a very important role in instilling healthy lifestyle habits. Studies have presented the benefits of physical activity and the harmful effect of screen-based sedentary behaviors on health in adolescents. It was found that children and adolescents who engage in physical activity every day, spend less than two hours a day in screen-based behaviors, do not do not use alcohol or other addictive substances, presented a higher likelihood of not having subjective health complaints (Marques et al., 2019). Promoting physical activity during development is a public health priority, and many studies emphasize the benefits of a variety of structured and unstructured activities in preventing non-communicable diseases and promoting health (Colella, Bellantonio, 2019). Daily structured and unstructured motor activities help to promote individual development of personality through balanced cognitive, motor and social development.

Individual healthy behaviour and a healthy lifestyle is related to less subjective somatic and psychological complaints such as headaches, feeling low, being irritated, feeling nervous and having sleeping disorders. The increased prevalence of problematic Internet use and subjective psychological health symptoms were reported by 15–16-year-old girls (Klavina et al., 2021).

Measuring daily physical activity is important to objectively monitor an individual's health. Consumer-based fitness trackers, like the Fitbit, have become popular among a variety of people, especially those who are physical active and interested in healthy behaviors. Activity trackers are developed to increase an individual's awareness about physical activity behavior through the day. Physical activity trackers can potentially stimulate users to increase their physical activity behavior (Kooiman et al., 2015). There is a large heterogeneity between activity tracker models in terms of available data types, the accuracy of recorded data, and how this data can be shared (Henriksen et al., 2021, Germini et al., 2022). It was found that physical activity measures were well correlated between the Fitbit and ActiGraph: 0.85 for moderate-to-vigorous physical activity and 0.94 for steps (all $P<.001$) (Van Blarigan et al., 2017). As researchers continue to improve commercially available physical activity trackers, the accuracy of these trackers' for physical activity registration needs to be evaluated.

It is found that a person's physical fitness and state of being influence his psychophysiological parameters (Podrigalo et al., 2019). Physical activity has not only been associated with increased physical and mental health, but also with beneficial effects on various cognitive and brain functions. Physical activity, especially physical education, improves classroom behaviors and benefits several aspects of academic achievement

(Álvarez-Bueno et al., 2017). It was found the beneficial influence of physical activity engendered through aerobic exercise on selective aspects of brain function (Hillman et al., 2008). Physical activity and lifestyle significantly affect various processes including the brain bioelectrical activity and vegetative functions of the body and, consequently, human cognitive functions (Popova et al., 2021). Physical activity has also been found to be an effective intervention to increase executive functioning in students with attention deficit hyperactivity disorder (Nakutin & Gutierrez, 2019). Exercise affects specific brain functions and therefore it has a significant effect on human cognitive function. The results of the study show a specific connection of the brain lobe with peripheral physiology, as well as the level of physical activity, perceived tension and dependence on the type of rest or exercise (John et al., 2020).

The aim of the study was to develop methodology and protocols for tracking adolescent's daily physical activities, sleep duration and quality, and assess dynamic of adolescent's motor skills and psychophysiological parameters. This case study showed full protocol of applied observation procedures used in PRIUSS research (see full observation data in Klavina et al., 2022). In the study were explored the effects of partly supervised physical exercise program (PSPEP) intervention compared to fully supervised physical exercise program (FSPEP) on cognitive functions, movement proficiency and problematic internet use (PIU) in adolescents presenting combined unhealthy lifestyle behaviors. As addition adolescent's daily activities were tracked with trackers devices FITBIT Inspire HR (https://www.fitbit.com) and ActiGraph wGT3X-BT (https://theactigraph.com).

Methodology

Participants

Over a period of 16 weeks the PSPEP group (n = 14) engaged in strength, balance and flexibility exercises three times per week with one supervised session and two unsupervised sessions. The FSPEP group (n = 13) practiced in dance activities for 2 to 4 days per week including in training sessions the same exercises as the PSPEP group. Prior and after the study adolescents completed the PIU scale, performed movement proficiency and cognitive function tests. In these interventions two types of physical activity tracker were used to monitor physical activity. In each group, 10 teenagers wore the FITBIT on the wrist and 5 of them simultaneously wore the ActivGraph device on the waist.

Adolescents' problematic Internet use was assessed by the Problematic and Risky Internet Use Screening Scale (PRIUSS), a validated screening instrument (Jelenchick et al., 2014). The PRIUSS is an 18-item risk-based screening scale for problematic Internet use with questions organized into 3 subscales: (1) social impairment (6 items), (2) emotional impairment (5 items), and (3) risky/impulsive internet use (7 items). The PRIUSS response selections use a Likert scale with scores of 0 through 4, including answers "never" = 0, "rarely" = 1, "sometimes" = 2, "often" = 3, and "very often" = 4. A PRIUSS score ≥ 26 indicates high risk for PIU; a score 15–25 indicates intermediate risk.

The motor skills of adolescents were assessed using the Bruininks – Oseretsky Bot-2 method (Bruininks & Bruininks, 2005, Bruininks-Oseretsky Test of Motor Proficiency, 2nd ed, (BOT-2), 2019). The Bruininks-Oseretsky test is a test individually developed for measuring of different motor abilities, in which targeted and effective tasks are performed to assess the development of small and large motor skills in people aged 4 to 21 years. Using this test, it is possible to determine the state of an individual's physical fitness and the delay in the development of motor abilities. Movement skills were assessed by four subtests of the Bruininks – Oseretsky Test of Motor Proficiency II (BOT -2): 1) bilateral coordination BC (7 items), 2) balance BAL (9 items), 3) running and speed RSA (5 items), and 4) strength STRG (5 items). The total point scores of the four subtests were calculated, and converted to scale scores, standard scores, percentiles, age-equivalents and descriptive categories for each subtest.

Students' psychophysiological parameters were assessed using Vienna tests before and after starting complex of physical activities. The tests have high values of validity and reliability, which have been confirmed by specially performed studies at the test development company "Schufrried" in Vienna (The Vienna Test System. Schuhfried, 2022).

The following Vienna tests were used: Cognitrone test (COG), Determination Test (DT), Adaptive Matrices Test (AMT), Figural Memory Test (FGT), Reaction Time Test (RT) and STROOP Test (STROOP).

COG test describes a person's work style, the speed of information processing, the persistence of attention and the ability to focus on work. During the test, the respondent must compare complex figures and decide on their identity.

DT test is used for measurement of reactive stress tolerance and ability to react under complex stimulus conditions. During the test, visual and acoustic signals are presented at high speed, to which an appropriate response must be given as soon as possible. The results of the test can be used to judge an individual's ability to work under stress.

AMT test is a non-verbal test that assesses general intelligence in terms of logical reasoning. Each test item consists of a stimulus part made up of nine fields, which is displayed in the upper part of the screen. Eight of these fields contain geometric configurations, while the final field contains a question mark. The eight configurations stand in some relationship to each other. The respondent's task is to identify these relationships and "replace" the question mark logically (correctly) with one of the eight patterns that are presented in the lower part of the screen. The variable General Intelligence assess the ability to draw non-verbal logical inductive conclusions.

FGT test is used to measure figural learning performance and figural episodic memory. The FGT test consists of several parts. The first part comprises five learning and reproduction runs in which 9 figures are presented repeatedly. Immediately afterwards the figures must be reproduced by means of simple mouse clicks on the screen. After a 5 minutes break this is followed by the second part, which requires free reproduction of the figures without a second viewing. The third part involves free reproduction after an extended delay (30 minutes), together with a forced-choice recognition task. The FGT test can be used to test memory for figural material.

RT test assesses the ability to react under simple stimulus. The use of a rest key and a reaction key makes it possible to distinguish between reaction and motor time.

STROOP test is a sensorimotor speed test that measures speed in reading words and naming colors under conditions of color/word interference. The respondent in the first part of the test must react according to the meaning of the written word (reading words), but in the second part of the test he or she must react according to the color of the written word (naming words). STROOP test assess the ability to inhibit cognitive interference that occurs when the processing of a specific stimulus feature impedes the simultaneous processing of a second stimulus attribute.

The complex of physical activities was developed by sports pedagogues. Students were introduced to physical exercises that had to be performed regularly. Physical activities were organized in the form of training group exercises, or by tasks which were given to students, and students filled these tasks individually. The level of physical activities was assessed with Fitbit fitness tracker and mobile applications.

Data from fitness devices were collected using appropriate platforms developed by manufacturers. For Fitbit adolescents synchronized their tracker with accounts in the FITBIT web-page, for ActiGraph sport pedagogues collected recorded data after intervention period using local application. In both cases collected physical activity data where processed and analyzed in Matlab (Matworks Inc, version 2020a) using self-developed script.

Statistical analyses were performed using IBM SPSS Version 28. Data analyses included descriptive statistics calculating means and standard deviations for groups descriptions, parametrical one-way ANOVA, and non-parametrical Kruskal-Wallis tests for comparing observed cognitive tests results with used statistical significance levels of $p < 0.05$ and $p < 0.01$ for these analyses.

Results

In Table 1 the results for problematic Internet use during the intervention are shown. In spite of increased physical activity level in PSPEP group, some adolescents increased also Internet usage intensity especially in emotional impairment scale. Perhaps, this can be explained by the fact that during the experiment there were restrictions due to the spread of COVID-19, so teenagers spent a lot of time in front of computers.

Table 1 PRIUSS test results

	PSPEP		FSPEP	
	Baseline values	After intervention value	Baseline values	After intervention value
Priuss (total)	13	28	14	15
Social Impairment	4	4	5	6
Emotional Impairment	4	15	3	3
Risky Impulsive Internet Use	5	9	6	6

In the Table 2 the summary of cognitive test's results is shown. Generally, the test results for both groups improved, although it seems that in PSPEP group some persons lost their motivation in participating in the study and did not perform at their best on the tests, resulting in slightly worse AMT intelligence test scores and slowdown of reaction time after the intervention period for these adolescents. AMT intelligence test scores after the intervention period for FSPEP group increased, and also reaction time became faster. On the other hand, adolescents in the PSPEP group performed better during the DT test, showing resistance to the stressful task conditions. DT test results also improved for FSPEP group after intervention period. In STROOP test reading and naming interference decreased for both groups. Results of COG and FMT tests did not much changed after intervention period.

Table 2 Cognitive function assessment outcomes

	PSPEP		FSPEP	
	Baseline values	**After intervention value**	**Baseline values**	**After intervention value**
AMT				
Intelligence Index	–1.528	–1.873	-–2.19	–0.624
Correct items	10	9	8	12
STROOP				
Reading interference (s)	0.277	0.081	0.072	0.06
Median RT – reading (s)	1.346	0.959	1.109	1.073
Naming interference (s)	-0.036	0.006	0.087	-0.013
Median RT – naming (s)	0.798	0.739	1.097	1.046
COG				
Sum correct reactions	54	56	55	55
Mean RT – correct reaction (S)	1.684	1.557	2.665	3.336
Sum incorrect reactions	6	4	5	5
Mean RT – incorrect reaction (S)	2.347	1.715	3.017	3.676
FMT				
Delayed free reproduction I	9	9	8	7
Delayed free reproduction II	9	9	8	8
Learning sum	17	18	16	16
Recognition – hits	8	8	8	8
DT				
Correct items	206	236	184	195
Number of stimuli	235	266	200	217
Reactions items	219	258	198	265
Median RT (s)	0.85	0.75	1.02	0.93
RT1				
Reaction speed RT6 (ms)	296	325	347	297

Table 3 BOT-2 test results

	PSPEP		FSPEP	
	Baseline values	**After intervention value**	**Baseline values**	**After intervention value**
BOT-2	126	130	118	121
BC	24	24	22	23
BAL	37	37	33	34
RSA	36	39	34	34
STRNG	29	30	29	30

BOT-2 – Test of Motor Proficiency, BC- bilateral coordination, BAL – balance, RSA – running and speed, STRG – strength.

A steady improvement in physical condition was observed in both groups with a greater improvement in running and speed parameters in the PSPEP group (see Table 3.). Test of Motor Proficiency results have improved in both groups (from 126 to 130 in PSPEP group and from 118 to 121 in FSPEP group).

Trackers recorded physical activity data

Both devices record activity levels by using internally build 3-axis accelerometer sensors. In this article, collected data for two persons were analyzed where data sets from two trackers devices were obtained. Actigrapfh in their calculation use all 24 hours' time slot therefor real physical activity cannot be detected for sedentary activity level. In this situation Fitbit shows more precise activity (steps and levels) because it additionally uses

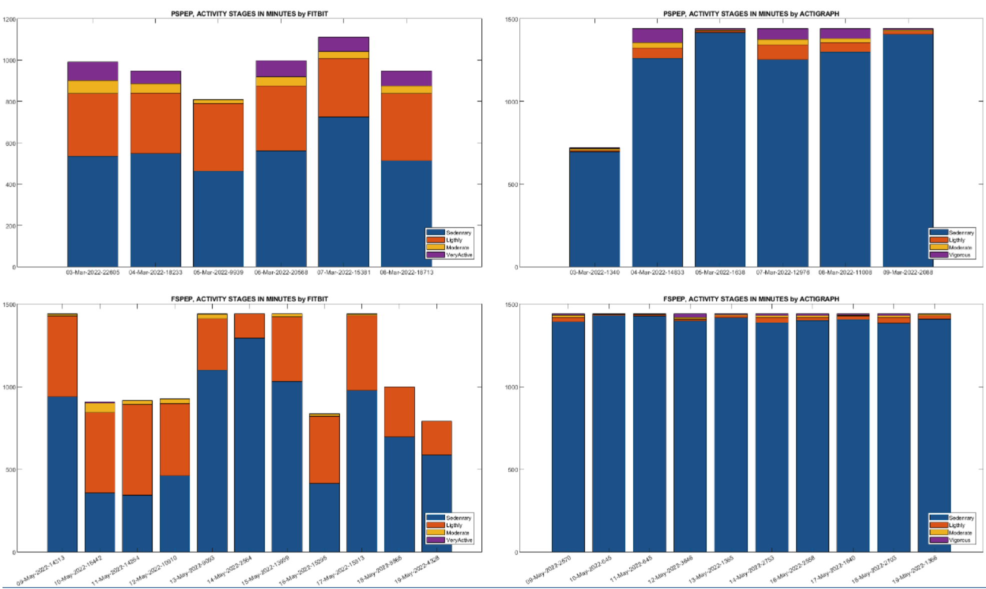

Figure 1 Physical activity in minutes FITBIT versus Actigraph (x-ass – observation days, y-ass time in minutes per stage. Stages of activities -Sedentary, Lightly, Moderate, Vigorous)

data from heart rate sensors. Activity levels in minutes recorded by FITBIT versus Actigraph data (see Figure 1) are completely different during adolescents' activity observation. In both groups adolescents didn't wear Actigraph device correctly during their day time activities. As a result, Actigraph high intensity stages (Moderate and Vigorous) in average were 2.5 minutes in PSPEP and 2.09 minutes in FSPEP, but in same time in FITBIT 51.01 and 9.46 minute respectively. In light activity stage by FITBIT data adolescents from PSPEP were 307.67 ± 17.65 minutes and FSPEP 379.27 ± 134.06 minutes.

Sleep stages

Sleep stages FITBIT calculated in minutes by following parameters: changes in movement activity and heart-rate. In one hour of inactivity trackers assumes that persons are asleep and second is changes in heart rate variability or beat-to-beat dynamics. During observation person from PSPEP group sleep's average 7.6 hours with relatively high sleep time variability across observation 1.7 hours. In FSPEP case average sleep is 9.1± 1.2 hours, in spite of these sleep time difference proportion of non-REM stages versus REM stage in both adolescents are almost similar 4.9 and 4.8. Sleep dynamic during observation time see in figure 2. Each sleep stage is measured in minute level.

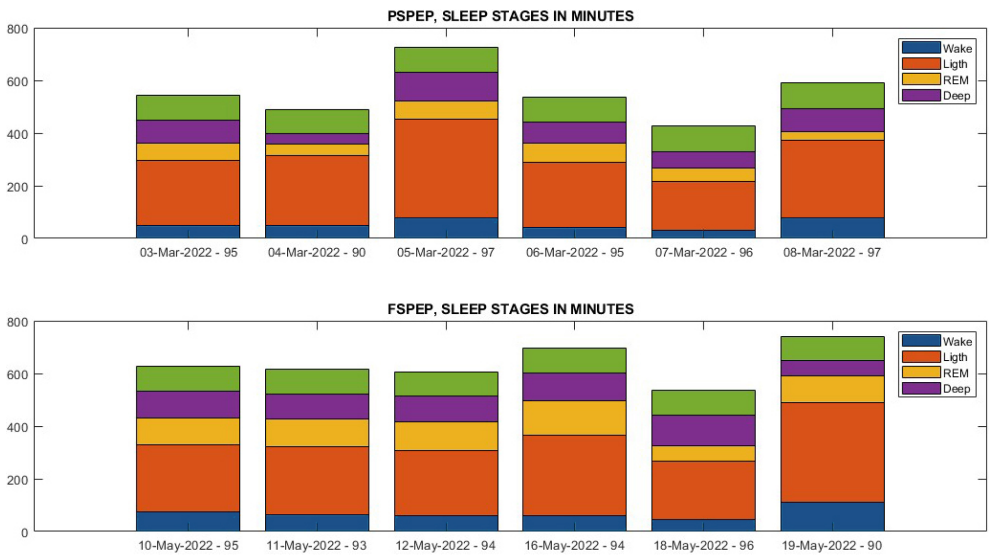

Figure 2 Sleep stages of adolescents (x-ass – observation days, y-ass time in minutes per stage. Stages of sleep – Wake, Light, Deep, REM)

Activity stages by heartbeat sensors data

FITBIT have addition activity tacking possibility using heart rate optical sensors data, as results addition activity zones (*Low, Moderate, High*) are calculated by device. In comparison with physical motion PSPEP participants have moderate and high activity for

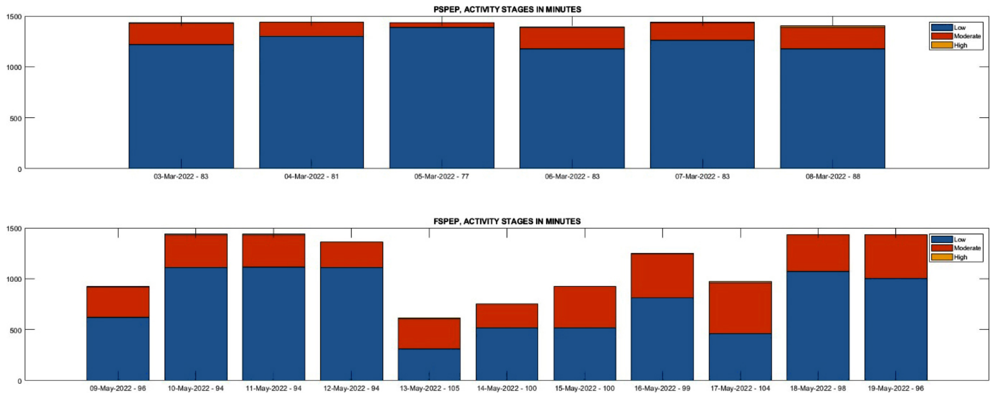

Figure 3 Activity stages by heartbeat sensors data (x-ass – observation days, y-ass time in minutes per stage. Stages of activities – Low, Moderate, High)

180.58 ± 79.51 versus 307.67 ± 17.65 minutes, and FSPEP 361.03 ± 91.12 versus 379.27 ± 134.06 minutes (see Figure 3).

Steps and Heart rate by Fitbit recordings

In Figure 4 time series of steps and heart rate (HR) are presented. Correlation between amount of the steps and HR per activity time period is clearly visible, especially in case of PSPEP group adolescent.

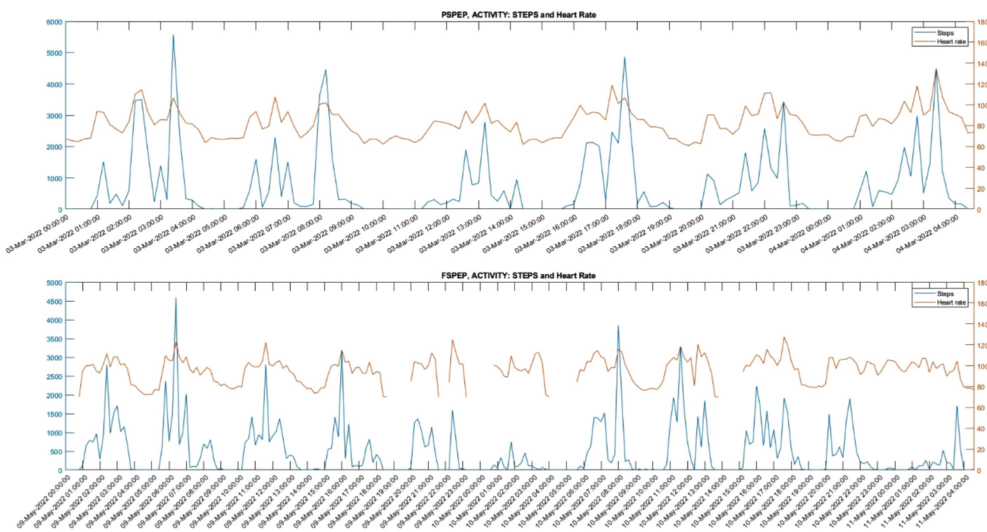

Figure 4 Steps and Heart rate by Fitbit recordings (x-ass – observation time line, y(right) -ass steps count per time y(left) -ass heart beat per minute)

Discussion

Investigators, using various consumer activity monitor models and smartphone models for measuring steps observed, that smartphone data collected at the hip, analyzed with a separate algorithm, performed either equally or even superiorly to the research-grade Actigraph (Hartung et al., 2020). The authors came to the conclusion, that measurement inaccuracies during intermittent walking and arm movements should be considered when interpreting study results and choosing activity monitors for evaluation purposes. Another authors have found that Fitbit shows better validity for estimating sedentary behavior and similar validity for assessing moderate to vigorous physical activity compared to the research-grade monitor (Kang et al., 2019).

Comparing of Fitbit and Actigraph use, the authors found high correlations and agreement between Fitbit and Actigraph, however, findings suggest also differences between the two devices (Chu et al., 2017). From specification perspective both tracking devices – Actigraph and Fitbit have 3-axis accelerometer sensors for motion tracking. Both devices have algorithms and hardware for sleep stages tracking. Fitbit device have built-in optical heart-rate sensor and this is optional with Polar heart rate monitor additional device in the Actigraph. Other differences between devices are the wearing locations (wrist, waist, arm, ankle) and 12 metabolic activity algorithms that are suitable for different age groups and physical exercises or continuous monitoring of activity in Actigraph.

One of the reasons that cause imprecise data from Actigraph was its physical dimension 46x33x15mm and weight 19g vs 16x37x13mm and weight 17g and for Fitbit and their external look. Results of our investigation show that adolescent's prefer wearing more convenient looking Fitbit devices with watch like display. Thus, although the Actigraph is a specific tracker that allows to capture various indicators, it is not necessarily suitable for young people in everyday use, and the Fitbit has some advantages over the Actigraph in everyday usage.

The use of tracing devices enables adolescents to engage in physical activities more actively on their own or under the guidance of educators, which promotes a more active lifestyle and also stimulates cognitive functions.

The developed methodology and protocols for tracking the adolescent's daily physical activities, sleep duration and quality and evaluating the dynamics of the adolescent's motor skills and psychophysiological parameters give the ability to follow the adolescent's lifestyle, physical and psychophysiological state.

Conclusions

Methodology for recording adolescent's physical activity, using tracking devices gave ability to record adolescent's physical and behavioural activity during the 16-weeks physical exercise program and compare it with their self-reported physical activities.

Fitbit fitness trackers are more preferable in comparison with ActiGraph because it is convenient easier to use them in partly supervised activity conditions, and it is possible to register sleep duration and heart rate changes with Fitbit.

Adolescents of both groups (PSPEP and FSPEP) showed improvements in physical test indicators and cognitive test parameters after partly or fully supervised physical exercise program intervention.

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