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By Mocanu George Dănut .

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Monitoring The Effort Curve In Physical Education For Normal And Overweight Students Using Smartwatches And Mobile Applications

Pârvu Carmen[1], Mocanu George Dănuț[1]*,Harabagiu Neculai[3], Ungurean Bogdan-Constantin[4], Szabo Dan Alexandru[5]

[1,2,3]Faculty of Physical Education and Sports, 63-65 Gării Street, Galati, "Dunărea de Jos" University. Romania

[4]Faculty of Physical Education and Sports, "Alexandru Ioan Cuza" University of Iași, Romania

[5]George Emil Palade University of Medicine, Pharmacy, Science, and Technology of Targu Mures. Romania

*Corresponding Author: Mocanu George Dănuț, e-mail: mocanu.george@ugal.ro

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Abstract

Study purpose. In physical education and sports lessons, correctly dosing effort is essential for optimising physical performance and adapting effort parameters, including breaks, in line with physiological principles. The study hypothesises that using smart-watches and mobile apps to monitor effort in middle school physical education lessons will reveal significant differences in effort and heart rate between overweight and average BMI students. Modern technology is expected to enhance understanding of students' physical exertion, facilitating adjustments to programs based on health status and fitness level.

Material and method. The study involved 45 students (average age 13.5 years) using 15 Xiaomi 8 smart-watches, phones, Wi-Fi, the Mi Fit app, and other devices to analyse body composition. Data on heart rate and BMI were collected during lessons, which followed the same theme and effort dosage. The Mi Fit app provided detailed aerobic and anaerobic exertion analyses. Parental consent was obtained, and data collection was done under routine lesson conditions. The technology aimed to improve performance and customise programs, offering a personalised approach to physical education. Real-time data transfer enabled accurate analysis of physical effort, promoting healthier lifestyles and better lesson adaptation by teachers.

Results. A significant interaction between heart rate and BMI steps ($p < 0.01$) shows different cardiovascular adaptations to exercise based on BMI. MANOVA confirmed the significant impact of these variables on heart rate, and post hoc comparisons showed differences between weight categories, except between overweight and extremely obese groups. These results highlight the need to tailor physical education programs to BMI categories to optimise cardiovascular health and performance.

Conclusion. Results suggest that monitoring the effort curve using modern technologies, such as smart-watches and mobile apps, provides valuable information for adjusting and optimising physical education lessons, especially for overweight and obese students.

Keywords. Exercise Curve, Heart Rate, Overweight And Underweight Students, Smart-Watch, Mobile Applications

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Introduction

Integrating modern technology to monitor physical activity in physical education classes is essential for assessing and optimising student performance. In physical education and sports lessons, effort dosing is essential for optimising physical performance and the correct adaptation of effort parameters about breaks, respecting the physiological principles of the organism. Analysis and comparison of the evolution of the "Gauss curve" (Ormenisan, Osorhean, Radu, & Rozsnyai, 2018) in this context provides a detailed understanding of the distribution of physical effort among students, contributing to optimising teaching strategies. Effort curve analysis, using mobile applications and smart devices such as smart-watches, is a topic of great relevance and complexity in contemporary physical education (Arensman et al., 2022; Babouras, Abdelnour, Fevens, & Martineau, 2024; Bayram, Ayhan, & Yalçin, 2023; Boswell et al., 2023; Dreimane, 2021; Gil-Espinosa, Nielsen, Romance Garcia, & Burgueño, 2022), as well as the development of other fields. These devices can collect a wide range of data about students' physical activity during lessons, including the number of steps taken, heart rate during the lesson, distance travelled, and calories burned.

This information is essential for assessing the appropriateness of physical exertion to students' individual needs and for optimising the structure of physical education lessons according to the set objectives. Monitoring the effort curve provides detailed data on physical activity and provides teachers with valuable information about pupils' health and progress in physical activity. This data allows individual trends and needs to be identified, making it easier to adjust teaching methods and targets for individual pupils. Implementing these technologies in the school curriculum improves students' motivation and involvement in physical activities, contributing to the effectiveness and quality of physical education lessons (Almasan, 2020; Dumitrache, VISAN; Gheorghe, Michalsik, Bădău, & Mereuță, 2022). These tools provide teachers with practical methods for performance assessment and classroom management, allowing for more informed and accurate decisions. Monitoring the exertion curve of students with weight problems is essential for managing physical activity in classes, as real-time data enables teachers to adjust activity intensity according to each student's abilities and needs.

For obese children, knowing their heart rate during exercise becomes essential to their health monitoring during physical activities. This measure not only helps to assess the intensity of exertion adequately but also to prevent physical overload and potential health complications. By using smart devices and mobile apps in this context, teachers and physical education specialists can obtain accurate and relevant data about the physiological response of obese students during physical activities. This information enhances the teaching and assessment process and contributes significantly to promoting a personalised and safe approach to the school physical activity program. Obese students may have a reduced capacity to sustain strenuous efforts. By tracking effort levels in real-time, teachers can adjust activities to maintain an appropriate pace and avoid premature exhaustion or risk of injury. Monitoring devices allow continuous assessment of progress in fitness and body weight management. This can motivate students to continue participating in physical activity and achieve their health goals. Knowing their heart rate during exercise teaches students the importance of maintaining a healthy heart rate and managing their physical activity safely and effectively. The integration of modern technologies in physical education can help raise the self-esteem of obese students by giving them concrete tools to engage and evaluate themselves in a controlled and friendly environment. Heart rate monitoring information can also be helpful for parents and health professionals in monitoring the general health of obese pupils. This collaboration can support a holistic approach to managing their health.

By implementing appropriate and educational real-time monitoring of exercise levels and heart rates in real-time, teachers can play a crucial role in improving their students' physical and general health, thereby helping to create a safer and more supportive school environment for all students. Analysing the topic in the literature, the study (Behzadnia, Adachi, Deci, & Mohammadzadeh, 2018) found significant associations between heart rate and various aspects of academic performance and executive function in children aged 9-13 years. Higher levels of physical activity, as indicated by heart rate monitoring, correlated with better academic performance and improved executive function. These findings highlight the potential benefits of integrating regular physical activity into school-aged children's daily routines to support their cognitive and academic development. Results suggest that heart rate monitoring during physical activity may be a valuable indicator for assessing and promoting students' well-being and overall performance. A study (Neshitov et al., 2023) demonstrated that wearable devices like the Apple Watch and Garmin can collect relevant data about heart rate and step counts from users' everyday lives. This data can be used to estimate VO2 max, an essential indicator of aerobic capacity. The machine learning model developed was trained on this data and was able to make accurate predictions of VO2 max comparable to direct estimates obtained in the laboratory. This suggests that wearables may provide an affordable and effective method for monitoring cardiorespiratory fitness without costly and invasive laboratory testing.

In order to verify that the model is not influenced by the unique measurement frequency of the devices, the heart rate data acquired was resampled to one measurement per minute during the preprocessing step. This method facilitated the merging and uniformity of data from many devices, hence guaranteeing the coherence and dependability of the machine learning model. This emphasises the importance of correct data preprocessing to obtain robust and applicable results across different contexts and wearable devices. In other research, tailoring exercise dosing by alternating exercise intensities and rest periods has also significantly improved physical performance and optimal physiological responses (El-Malahi et al., 2024). In the study (Liu et al., 2023), the authors analysed the impact of different structures of physical education lessons on the development of aerobic capacity in middle school students. Heart rate was used as the leading indicator of exercise intensity. In another study where modern heart rate monitoring technologies were used (Chen & Liu, 2024; Liu et al., 2023) the authors investigated the influence of exercise dosing and scheduled breaks on heart rate and perceived fatigue in high school physical education lessons.

The cardiovascular system activity study (CVS) presented by the authors (Hills, Dengel, & Lubans, 2015; Neshitov et al., 2023; Turdimuratov, Auezovich, & Urgenishbaevich, 2023; Zilio et al., 2024) is of significant importance in assessing the functional status of students during physical education and sports lessons. The observed adaptations in CVS, both at rest and in response to physical activity, provide essential information not only about the functional status of the cardiovascular system but also about the body's general state. In the context of physical education, the assessment of parameters such as heart rate, blood pressure and recovery time after exercise, using standardised tests such as the Martinet test, helps to determine students' adaptive capacity and physical health. In conclusion, integrating smart-watches and other physical activity monitoring technologies into physical education and sports brings significant benefits in terms of health promotion and improved student performance. These devices not only respond to the current needs of today's tech-savvy generations but also contribute to modernising the educational process, ensuring a more attractive and practical learning environment for students.

The primary aim of this research is to analyse the trajectory of the effort curve during physical education and sports lessons, investigating whether it follows an upward trend in the first three stages and a downward trend in the last three stages. This analysis will be carried out by monitoring and assessing heart rate at each stage, using modern technologies such as smart-watches connected to mobile apps. In addition, the aim is to identify physiological differences, as measured by heart rate, between students assigned to the four body mass index categories (average weight, overweight, obese and underweight). Also, this research aims to explore how mobile apps and smart-watch devices can be effectively integrated into middle school physical education lessons to analyse and optimise the effort curve, considering the distinct differences between overweight and normal-weight students.

Materials and Methods

We hypothesise that the use of smart-watches and mobile applications to monitor the effort curve in physical education lessons in middle school students will allow the identification of significant differences in effort level and heart rate between overweight and average body mass index students. Thus, we hypothesise that modern technology will provide a better understanding of the physical education profile of students, facilitating appropriate adjustments of physical education programs to meet the specific needs of each student based on their health and fitness level.

Study Participants

The research was conducted in April 2024 in the educational unit: " Holy Emperors Secondary School" from Galati, Romania, and the subjects were 45 students from the 8th grade with the age of 13.5 years (±0.7). Initially, measuring the four classes of students was desired, but due to connectivity problems and unforeseen situations during the measurements, only 45 validated participants were left to participate in the study. For this study, 15 Xiaomi 8 band smart watches were used („Xiaomi Smart Band 8 | Mi-Home.ro", f.a.), students' phones, wi-fi and the Mi fit mobile app (MI FIT, f.a.), a Lenovo tablet with the Garmin Connect app (Garmin & subsidiaries, f.a.-a) and a Garmin scale (Garmin & subsidiaries, f.a.-b)that analyses body composition. Xiaomi Band 8 is equipped with a range of sensors designed to monitor physical activities and biometric parameters, including an accelerometer that tracks movement and acceleration on three axes to detect activities such as steps and workouts, an optical heart rate sensor (PPG) that monitors heart rate by measuring blood flow variations, and a SpO2 sensor that estimates blood oxygen levels. Additionally, it includes a proximity sensor that activates or deactivates the screen based on hand movements, as well as an ambient light sensor that automatically adjusts the screen brightness according to the surrounding light conditions.

Mi Band 8 uses arm movements to track steps, and for data accuracy, we have calibrated the band so it can accurately count your steps depending on whether you are walking or running. The calibration process was performed through the Mi Fit app under the "Profile" tab by pressing the "Calibrate" button as outlined in the user manual available in (MI FIT, f.a.). The connection of the devices took place in the lesson before the measurement, and consent statements (signed by the legal representatives) regarding the processing of personal data and the agreement to participate in the study were also collected. The homeroom teacher coordinated the lessons, and all 4-8th grade classes were only required to keep the same homework and the exact dosage of effort. After applying the clocks on the hands of the students, the end minutes of each link of the lesson were noted like this: the minute after the first link, the minute after the second link, and so on, so that when collecting data from the application we have the heart rate values after link 1, link 2, link 3, link 4, link 5, link 6 and link 7 of the lesson (without the 8th link of the lesson).

Although the apps provided us with a variety of data about the subjects, in this study, our focus was only on heart rate measured at seven distinct times during the lesson, weight and height to determine the 4 Body Mass Index steps (underweight, average weight, overweight and obese). Also relevant to the research, we also noted the option that the Mi Fit app calculates, which, based on the analysis of oxygen consumption and heart rate monitored, determines how the physical effort was felt by the body, showing in percentage and minutes how much it was felt as aerobic, anaerobic.

Study organization

In order to obtain accurate data, students were informed in advance, and the classes were conducted under normal conditions. The lesson was carried out following the order of the links in order to collect at the end of the lesson a set of data to make a comparison with the data written in the specialised literature and to compare the heart rate of the four categories of students (underweight, average weight, overweight, obese). These advanced technologies aim to increase physical performance in the lessons and adapt the training programs according to the student's individual needs, thus contributing to a personalised and practical approach to physical education.

The detailed research methodology proposed a rigorous and systematic approach to implementing smart-watch technology and mobile applications in the context of physical education lessons at the middle school level. Through well-defined stages, starting from the formulation of the main hypotheses and the working strategy to the purchase of the necessary equipment from the funds allocated to "***Prima Didactică***", our study is intended as a guide for the dosage of effort in physical education lessons through the objective, real-time evaluation of the parameters of student effort. Familiarisation with the selected applications and their proper set-up for collecting the relevant data was cumbersome due to the lack of literature and methodologies. The selection and training of subjects, including obtaining the necessary consents from parents or legal representatives for student participation in the research, were essential steps in ensuring the fair and ethical implementation of the study.

Connecting a smartwatch to a mobile app involves activating Bluetooth on both devices, downloading and installing a compatible app (from the App Store for iOS or the Google Play Store for Android) on the smartphone, followed by initial account setup and data synchronisation through a dedicated pairing process seen in figure 1.

Figure 1. Connecting the Xiaomi 8 band watch to the MI Fit app and sending data to phones

This method efficiently monitors physical exertion during lessons, allowing real-time data transfer up to 20 meters away without limiting the subjects' execution and facilitating subsequent storage and analysis.Implementing a real-time and objective assessment system of effort parameters in physical education lessons brings multiple benefits to students, teachers and the education system. Through immediate and objective feedback, pupils are encouraged to adjust their efforts responsibly and improve their physical performance. Teachers can use accurate data to tailor lessons to individual student needs and better assess their progress.

Improving students' physical health and motivation can contribute to more active participation and more effective learning during 45-minute physical education and sports lessons in Romanian schools. Additionally, promoting a healthy lifestyle and efficiently managing resources in schools through the physical effort exerted in PE lessons are essential aspects for the overall development of the education system. The stages of the study complied with the ethical rules for research involving human subjects, as stated in the Declaration of Helsinki.

Statistical analysis

Statistical calculations were performed with SPSS (Statistical Package for the Social Sciences - Vers.26). We applied ANOVA for repeated measures to examine differences in heart rate (H.R.) according to lesson links and weight categories (BMCtrepts). The results showed significant differences between links and weight categories, with a significant interaction between these variables. All ANOVA tests (Pillai's Trace, Wilks' Lambda, Hotelling's Trace, Roy's Largest Root) were significant ($p < 0.001$), suggestive of a significant difference in heart rate across lesson links. The interaction between heart rate per link and B.M.C. steps was significant ($p < 0.01$), indicating that the effect of heart rate varies across weight categories. We also utilised MANOVA (Multivariate Analysis of Variance) to simultaneously assess the combined effects of the links (FCverigi) and B.M.C. steps (underweight, average weight, overweight, significantly overweight) on a set of dependent measures (heart rate) considering their interaction.

The sphericity test was significant ($p < 0.001$), indicating that sphericity was not assumed. We applied Greenhouse-Geisser and Huynh-Feldt corrections. Pairwise comparisons Post Hoc Test for B.M.C. steps showed significant differences between underweight, average weight and overweight, but not between overweight and highly overweight.

Results

The following table 1 shows the descriptive values of heart rate (beats per minute) for various body mass index (B.M.I.) categories in the seven tracked links of the physical education lesson. (excluding the eighth link) These links are distinct stages or times at which heart rate was measured. The table provides information about the mean (Mean), standard deviation (Std. Deviation), and number of subjects (N) for each combination of B.M.C. category and link.

Table 1. Descriptive Statistics of Heart Rate by Body Mass Index (BMI) and Measurement Methods

	B.M.C. climbers	Mean	Std. Deviation	N
Heart rate after the first link	underweight	106,14	17,141	14
	normal- weight	99,06	12,337	16
	overweight	117,25	17,903	8
	extreme overweight	116,71	13,732	7
	Total	107,24	16,511	45
Heart rate after link2	underweight	120,79	20,911	14
	normal- weight	117,31	14,809	16
	overweight	138,13	12,253	8
	extreme overweight	142,29	5,057	7
	Total	125,98	18,340	45
Heart rate after link 3	underweight	139,21	13,622	14
	normal- weight	130,31	9,293	16
	overweight	150,75	7,704	8
	extreme overweight	160,57	4,077	7
	Total	141,42	14,716	45

Heart rate after link 4	underweight	141,57	19,230	14
	normal- weight	149,56	10,608	16
	overweight	174,25	5,946	8
	extreme overweight	180,86	7,448	7
	Total	156,33	20,022	45
Heart rate after link 5	underweight	134,57	18,875	14
	normal- weight	144,44	9,458	16
	overweight	171,13	12,182	8
	extreme overweight	172,86	13,031	7
	Total	150,53	20,820	45
Heart rate after link 6	underweight	129,43	24,248	14
	normal- weight	131,13	14,769	16
	overweight	150,38	17,196	8
	extreme overweight	138,71	17,144	7
	Total	135,20	19,891	45
Heart rate after link 7	underweight	93,3571	4,95529	14
	normal- weight	94,9375	6,31895	16
	overweight	117,1250	5,86606	8
	extreme overweight	110,4286	7,97615	7
	Total	100,8000	11,32897	45

Analysing the above data from the table 1, we observe that underweight students had a mean heart rate of 106.14 (SD = 17.14), normal overweight students 99.06 (SD = 12.34), overweight students 117.25 (SD = 17.90), and highly obese students 116.71 (SD = 13.73). Differences between groups suggest that students with higher B.M.I. experience more significant cardiovascular effort from the onset of physical activity. The mean heart rate values after the second link were 120.79 (SD = 20.91) for the underweight, 117.31 (SD = 14.81) for the normal-weight, 138.13 (SD = 12.25) for the overweight and 142.29 (SD = 5.06) for the extremely obese. These data reflect a significant increase in cardiovascular effort in overweight and extremely obese students.

After the third link, the underweight students had a mean heart rate of 139.21 (SD = 13.62), the regular overweight 130.31 (SD = 9.29), the overweight 150.75 (SD = 7.70) and the highly obese 160.57 (SD = 4.08). These values indicate a heightened cardiovascular response as the effort continues, especially in those with a higher B.M.I.

After the fourth link, means of 141.57 (SD = 19.23) for underweight, 149.56 (SD = 10.61) for average weight, 174.25 (SD = 5.95) for overweight and 180.86 (SD = 7.45) for extreme obesity suggest significantly increased cardiovascular stress for students with high B.M.I.

After the fifth yard, the underweight students had a mean heart rate of 134.57 (SD = 18.88), the regular overweight 144.44 (SD = 9.46), the overweight 171.13 (SD = 12.18) and the highly obese 172.86 (SD = 13.03). This shows a significant difference between groups regarding cardiovascular response to exercise.

After the sixth link, the values were 129.43 (SD = 24.25) for the underweight, 131.13 (SD = 14.77) for the average weight, 150.38 (SD = 17.20) for the overweight and 138.71 (SD = 17.14) for the extremely obese. Even after prolonged exertion, students with higher B.M.I. maintained elevated heart rates, indicating difficulty in recovery. Means of 93.36 (SD = 4.96) for underweight, 94.94 (SD = 6.32) for average weight, 117.13 (SD = 5.87) for overweight and 110.43 (SD = 7.98) were recorded after the seventh link, and for those with extreme obesity suggest a lower recovery capacity in overweight and extremely obese students.

Overweight and extremely obese students have significantly higher baseline heart rate values than underweight and average overweight students, indicating more significant cardiovascular stress at the onset of exercise. As exercise intensity increases, the differences between B.M.I. groups become even more pronounced, with overweight and extremely obese students showing marked increases in heart rate. The cardiovascular response in the intermediate stages of exercise shows that students with higher B.M.I. have a more difficult adaptation, suggesting the need for personalised training programs. In the final stages of exercise, overweight and highly obese students have incredibly high heart rate values, emphasising continuous cardiovascular stress. Post-exertional recovery capacity is significantly lower in students with higher B.M.I., highlighting the need for specific interventions to improve their recovery capacity, can be seen in table 2.

Table 2. Multivariate Tests of the Effects of Body Mass Index (B.M.I.) and Vertiles on Heart Rate

Effect		Value	F	Hypothesis df	Error df	Mr.	Partial Eta Squared	Noncent. Parameter	Observed Power[d]
FCverigi	Pillai's Trace	,965	167,006[b]	6,000	36,000	,000	,965	1002,036	1,000
	Wilks' Lambda	,035	167,006[b]	6,000	36,000	,000	,965	1002,036	1,000
	Hotelling's Trace	27,834	167,006[b]	6,000	36,000	,000	,965	1002,036	1,000
	Roy's Largest Root	27,834	167,006[b]	6,000	36,000	,000	,965	1002,036	1,000
FCverigi * BMCtrepte	Pillai's Trace	,763	2,160	18,000	114,000	,008	,254	38,874	,978
	Wilks' Lambda	,379	2,326	18,000	102,309	,004	,276	39,072	,977
	Hotelling's Trace	1,266	2,439	18,000	104,000	,003	,297	43,898	,989
	Roy's Largest Root	,811	5,136[c]	6,000	38,000	,001	,448	30,813	,984

a. Design: Intercept + BMCtrepte
Within Subjects Design: FCverigi
b. Exact statistic
c. The statistic is an upper bound on F that yields a lower bound on the significance level.
d. Computed using alpha = .05

The multivariate analysis (MANOVA) revealed significant effect of effort links on heart rate (Wilks' Lambda = 0.035, F(6, 36) = 167.006, p < 0.001, \(\eta_p^2 = 0.965 \))) and a significant interaction between the exercise links and B.M.I. categories (Wilks' Lambda = 0.379, F(18, 102.309) = 2.326, p = 0.004, \(\eta_p^2 = 0.276 \)), indicating significant differences in physiological responses to exercise as a function of students' B.M.I. The interaction between effort links and B.M.I. categories is significant, suggesting that the heart rate response to exercise differs according to students' B.M.I. This emphasises the need to tailor physical education programs to meet the specificities of each B.M.I. group. The very high observed power for all tests suggests that the study can detect the true effects of the effort links and their interaction with B.M.I. categories.

Table 3. Comparison of Heart Rate by Body Mass Index (B.M.I.) - L.S.D. Post Hoc Test

Measure: Heart rate

L.S.D.

(I) B.M.C. climbers	(J) B.M.C. climb	Mean Difference (I-J)	Std. Error	Mr.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
underweight	normal- weight	-,2398	3,03322	,937	-6,3655	5,8859
	overweight	-21,9898*	3,67342	,000	-29,4084	-14,5712
	extreme overweight	-22,4796*	3,83676	,000	-30,2281	-14,7311
normal- weight	underweight	,2398	3,03322	,937	-5,8859	6,3655
	overweight	-21,7500*	3,58896	,000	-28,9981	-14,5019
	extreme overweight	-22,2398*	3,75598	,000	-29,8251	-14,6544
overweight	underweight	21,9898*	3,67342	,000	14,5712	29,4084
	normal- weight	21,7500*	3,58896	,000	14,5019	28,9981
	extreme overweight	-,4898	4,28963	,910	-9,1529	8,1733
extreme overweight	underweight	22,4796*	3,83676	,000	14,7311	30,2281
	normal- weight	22,2398*	3,75598	,000	14,6544	29,8251
	overweight	,4898	4,28963	,910	-8,1733	9,1529

Based on observed means.

The error term is Mean Square(Error) = 68,697.

*. The mean difference is significant at the ,05 level.

As can be seen from table 3 differences were found in several cases in the multiple comparative analyses of heart rate between categories of pupils according to body mass index (B.M.I.). Normal-weight students had significantly lower heart rates than overweight and extremely overweight students ($p < 0.001$), with a mean discrepancy of approximately 22 beats per minute. Underweight students also had lower heart rates than overweight and significantly overweight students, with a significant difference ($p < 0.001$) of approximately 22-23 beats per minute.

In contrast, there were no significant differences in heart rate between overweight and significantly overweight students ($p = 0.910$), suggesting a similarity in the physiological response of these two categories of students in physical education and sports lessons. These findings underline the importance of managing individual differences in body mass index in tailoring and optimising exercise programs for secondary school students.

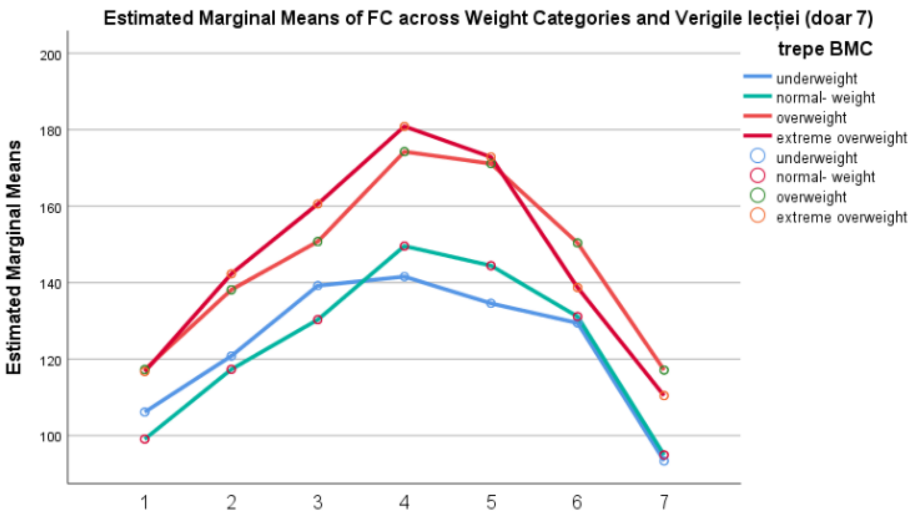

Figure 3. Heart rate evolution by weight category during the lesson links (only seven links, without link 8)

The Figure 3 presents the estimated marginal heart rate values for seven heart rates across four body mass index (BMI) categories: underweight, average weight, overweight, and extreme obesity. Across all BMI categories, the effort curve rises steadily during the first four phases, peaking at phase 4, before gradually declining until phase 7. Initially, heart rate values are comparable across categories, with a slight increase from underweight to extreme obesity. All categories reach their maximum exertion at phase 4, indicating the peak of physical activity. Following this peak, heart rates decrease progressively, suggesting reduced intensity or a recovery phase. Notably, the underweight group consistently showed lower heart rates, indicating a less intense cardiovascular response to exercise.

After the fourth week, heart rate progressively decreases in all categories. This indicates reduced exercise intensity and a possible transition to less demanding activities or recovery phases. The underweight had lower heart rate values throughout exercise, suggesting a less intense cardiovascular response to exercise. The elevated heart rate values in overweight and extremely obese students suggest a higher cardiovascular workload. This may indicate a lower efficiency of the cardiovascular system or lower physical fitness compared to the other groups. It indicates a predominance of anaerobic metabolism, suggesting high exercise intensity during this phase. The trajectory of the exercise curve follows a typical pattern of physical exertion, with a warm-up phase, a peak intensity and a recovery phase. In links 5-7, heart rates gradually return to lower levels, corresponding to aerobic exertion, as physical activity nears the end or includes recovery phases.

The existence of notable differences between B.M.I. categories indicates that overweight and extremely obese students experience more significant cardiovascular stress during physical activity. This may have implications for how physical education lessons are structured, tailoring exercise intensity to ensure the safety and effectiveness of training for all students. This interpretation highlights the need to tailor the physical education program to students' individual characteristics, using modern technologies to monitor and adjust physical exertion accordingly. By analysing the effort curves in the Mi Fit app "Status", where the workout load is calculated based on the excessive oxygen consumption after exercise (statistic provided on the app), we notice that:

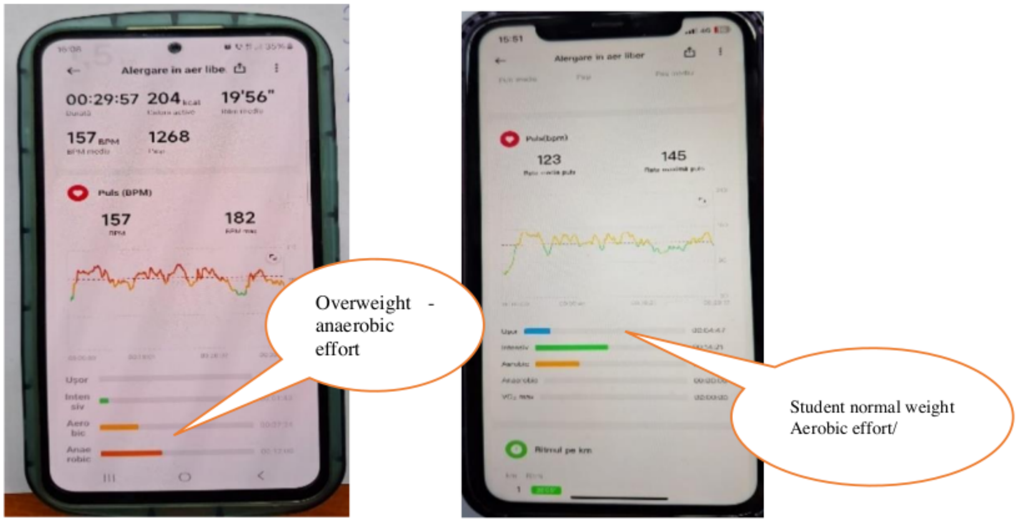

Figure 4. Mi Fit app "Training status" option (a - overweight student and b - average weight student)

In the figure 4 above (a), we present the Mi Fit app with data from a student with obesity. In the 29 minutes of monitoring, there was 1 minute and 43 seconds of intense exercise, 12 minutes of anaerobic exercise and 7 minutes of aerobic exercise. In the same physical education lesson, with the exact effort dosage, the normal-weight student, as shown in Figure 4 (b), experienced a light effort of 4 minutes and 47 seconds, an intensive effort of 14 minutes and 21 seconds, an aerobic effort of 8 minutes and 33 seconds and an anaerobic effort of 0 minutes.

From the research results and the data provided by the mobile app, we observe that **underweight and normal-weight** students maintain lower heart rates during exercise, suggesting a better cardiovascular capacity and a more efficient transition between aerobic and anaerobic effort. Underweight students remain predominantly in the aerobic zone even at peak effort, suggesting good endurance at moderate effort. **Overweight and extremely obese students** have higher heart rates, exceeding the anaerobic threshold faster and for more extended periods. This indicates higher cardiovascular workload and lower efficiency in the aerobic and anaerobic metabolism transition.

Discussion

Starting from the aim of our study, namely, the detailed analysis of the trajectory of the effort curve during physical education and sports lessons, investigating whether it follows an upward trend in the first three stages and a downward trend in the last three stages, we can state that it has been fulfilled. Physical education teachers can use valid, low-cost subjective techniques to monitor students' effort intensity as an alternative to new, expensive technologies (Badicu, Nobari, González Valero, & Sánchez, 2022; Bădicu, 2018; Mocanu, Murariu, Iordan, & Sandu, 2021; Mocanu & Onu, 2022). Study (García-Ceberino, Gamero Portillo, Ibáñez, & Feu, 2022) demonstrated significant positive correlations between intensities measured by objective (inert devices and heart rate monitors and subjective (task analysis sheets and perceived exertion ratings) techniques, suggesting that the high-intensity values measured using objective approaches align with the high-intensity values measured using subjective techniques, and vice versa. Despite occasional poor correlations, the findings endorse using subjective methods for planning and monitoring the degree of effort in physical education programs since they are convenient to implement within a school setting (Tashpulatov, 2024; Мухиддин, Ташпулатов, & Khamraeva, 2024)

Gaining insight into the correlation between heart rate and physical activity is crucial for fitness instruction. Utilising a heart rate monitor (H.R.M.) aids students in comprehending the correlation between significant muscle movements and stretches, which gradually elevate heart rate and blood circulation. This enables them to gauge their heart rate while exercising and establish objectives for maintaining the suitable target heart rate zone based on age and individual condition. Integrating heart rate monitoring into physical education enhances students' comprehension of heart function and the need to maintain sufficient physical activity. This approach also stimulates their drive to attain and sustain individualised fitness objectives. By incorporating these interdisciplinary courses and using H.R.M.s efficiently, pupils' health and physical performance may be significantly enhanced (Muntaner-Mas, Vidal-Conti, Salmon, & Palou-Sampol, 2020).

A study of interest for our topic (Stöckel & Grimm, 2021) emphasises that real-time heart rate feedback during physical education classes can enhance students' autonomous motivation and physical effort. Cardiovascular fitness education programs in physical education classes, including heart rate monitors, can counteract children's sedentary lifestyles and promote a healthy and active lifestyle. These programs provide individualised instruction and assessment, increasing student responsibility and motivation for long-term fitness. Data collected by heart rate monitors can be shared with parents, improving collaboration between physical education specialists and families. The example of the Heart Health Tomorrow's Wealth program at Alimacani Elementary School demonstrates the effectiveness of these initiatives in increasing students' motivation for lifelong physical activity and providing valuable information about the effectiveness of physical education.

Heart rate monitors in physical education lessons can supplement traditional teaching methods, providing students with individualised instruction and a sense of competence and autonomy. Although most students appreciated the use of the monitors and expressed interest in their continued use, there are challenges related to the effective implementation and convenience of the devices. Heart rate monitoring showed sizeable individual variation, and achieving the recommended 50% moderate to vigorous physical activity (MVPA) during lessons is difficult. However, heart rate monitors can improve student engagement and help promote an active lifestyle. A study (Muntaner-Mas et al., 2020) revealed modest associations between children's heart rate measures during physical education lessons and academic performance but did not indicate links with executive function. Academic performance was positively associated with four heart rate measures and high heart rate intensity levels in two academic indicators. Conversely, the connections between heart rate measurements and executive function were less evident. These findings highlight the need for further empirical investigations to examine the connections between varying degrees of physical exercise intensity and brain function in children to elucidate these interactions.

One research (Ma, Yu, Bekker, Hu, & Vos, 2020) introduces FitBirds, a multiplayer fitness game that aims to motivate teenagers to engage in physical activity at an optimal intensity level, which is continuously adjusted in real-time according to their heart rate. The FitBirds game incorporates competitive and cooperative game features to boost teenagers' entertaining experiences and social engagement. This, in turn, may lead to more consistent active physical involvement in physical education. An exploratory study (Permadi, A. A., Solahudin, S., Sonjaya, A. R. & Arifin, Z., 2023) found that using heart rate monitors in physical education classes influences students' perceptions of physical education classes. Three major themes emerged from the data analysis: the use of monitors to assess physical education grades, students' perceptions of their fitness level, and the consistency of instructors' use of monitors. These perceptions affect student motivation, and implementing technology consistently and clearly can positively influence students' intrinsic motivation. The study suggests the need for future research to explore ways technology can effectively enhance students' motivation and active participation in physical education classes.

Implementing M.B.I., especially the Sports Education Model, and technological feedback, such as heart rate monitors, can significantly improve students' performance and active participation in physical education (Bahadirovna, 2023; Layne, Simonton, & Irwin, 2022; Warwuru & Umakaapa, 2022). These approaches improve physical outcomes and increase student motivation and engagement, thus creating a more effective and collaborative educational environment. The study (Oliva Lozano, Martín Fuentes, & Muyor, 2019; Wati, 2023) involved sixteen male students, mean age 14.40 years, in a physical education session monitored by the WIMU Fit system and GARMIN heart rate monitors. The 60-minute activity included a warm-up, a basketball game and a cool-down. Data collected included average and maximum heart rate, energy expenditure and time spent in each heart rate zone, categorised into five intensity zones. Real-time heart rate monitoring allowed a detailed and individualised interpretation of the data for each participant. The study demonstrates the usefulness of advanced technology in physical education in providing real-time feedback and personalising exercise intensity monitoring, thus contributing to better assessing and motivating students in physical activities.

A study (Slavinsky, Kuznetsova, & Yatkin, 2023) highlights that physical activity significantly impacts students' cardiovascular health. Using a particular set of exercises and the Ruffier test, an improvement in heart rate variability and cardiac performance was observed. These exercises, which include sports games and competitions, contribute to the activity of the autonomic nervous system, particularly the balance between sympathetic and parasympathetic departments. The overall conclusion is that the regular practice of sports and physical culture has a significant positive effect on students' general health. The results of the experiment conducted with students of Kuban State Agricultural University show significant differences between the health indicators of men and women during physical training and at rest. The measurements were carried out using a moderate-intensity health complex and the Ruffier test, which allowed for the assessment of cardiac performance and heart rate variability. The study emphasises the need to integrate sports activities like volleyball and badminton to stimulate autonomic nervous system activity and improve young people's health. The conclusion is that regular physical activity significantly improves students' heart function and overall health.

One study (Reis et al., 2024) emphasises that to achieve the fitness and physical activity goals set in physical education lessons, children must regularly participate in moderate to vigorous physical activity (MVPA). Moderate physical activity is defined as reaching a heart rate at 50% of maximum heart rate reserves (MHRR), moderate-vigorous activity at 60% of MHRR, and vigorous activity at 75% of MHRR for at least 20 minutes or 50% of the lesson time. Previous studies have shown that most P.E. lessons do not meet these criteria, highlighting methodological and analytical problems. However, lessons that directly aimed to increase MVPA were successful. In order to achieve the curricular goals of physical activity and fitness, a greater focus on physical activity in the planning and delivery of physical education lessons is needed. Advances in research based on applications in performance sports using technologies for team game analysis, movement analysis, effort measurement, progress assessment, health ssassessment, and cognitive accessibility are increasingly being promoted for the benefit of coaches, teachers, athletes, healthy and disabled students (Hubbard, 1993; Permadi, A. A., Solahudin, S., Sonjaya, A. R. & Arifin, Z., 2023; Sykora, Chung, Folland, Halkon, & Edirisinghe, 2015; Utama, Doewes, Ekawati, & Németh, 2023).

The first problem encountered was related to parental control; some of the students could not install the application. The second problem encountered was the refusal of pupils to be weighed, even individually, anonymously. The major limitation in conducting the research was that the overweight and overweight students had moments when they stopped the effort during the physical education lesson, so the data provided were subject to changes; The cumbersome way of collecting data is caused by the fact that each smart-watch Xiaomi 8 band sends data to only one phone; the app collects data individually, requiring 15 phones to be connected to the 15 smart-watches.

Conclusions

The results suggest that detailed monitoring of the effort curve using modern technologies like smartwatches and mobile apps can provide valuable insights for adjusting and optimizing physical education lessons, particularly for overweight and extremely obese students. Heart rates differ significantly between normal-weight individuals and those who are overweight or extremely obese, with overweight individuals showing higher heart rates compared to underweight and normal-weight individuals. Similarly, extremely obese individuals exhibit higher heart rates compared to both underweight and normal-weight individuals, although no significant difference is found between overweight and extremely obese individuals.

Multivariate tests confirm significant effects of different phases on heart rate, indicating that heart rate varies depending on the phase of physical activity and the body mass category. The analysis shows a strong effect, explaining a considerable portion of the variation in heart rate, with high reliability in detecting real effects.

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Conflicts of Interest

The authors declare no conflict of interest.

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Information about the authors:

Pârvu Carmen.: carmen_preda06@yahoo.com, **https://orcid.org/0000-0002-2910-9494**, Faculty of Physical Education and Sports, 63-65 Gării Street, Galati, "Dunărea de Jos" University. Romania

Mocanu George Dănuț.: carmen_preda06@yahoo.com, **https://orcid.org/0000-0002-3534-5055**, Faculty of Physical Education and Sports, 63-65 Gării Street, Galati, "Dunărea de Jos" University. Romania

Harabagiu Neculai.: neculai.harabagiu@ugal.ro, **https://orcid.org/0000-0001-7978-0553**, Faculty of Physical Education and Sports, 63-65 Gării Street, Galati, "Dunărea de Jos" University. Romania

Ungurean Bogdan Constantin.: ungurean.bogdan@uaic.ro, **https://orcid.org/0000-0001-9596-2162**, Faculty of Physical Education and Sports, "Alexandru Ioan Cuza" University of Iași. Romania

Szabo Dan Alexandru.: dan-alexandru.szabo@umfst.ro, **https://orcid.org/0000-0002-7326-212X**, George Emil Palade University of Medicine, Pharmacy, Science, and Technology of Targu Mures. Romania

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