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Original Article

24 Hour monitoring and comparative analysis of cardiac activity peaks in pre-adolescents across sports, school, and leisure using advanced technologies: A comprehensive review of scientific literature

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Abstract
Background: Limited research exists on heart rate (HR) in children, particularly regarding its maximum values (HRmax). This study aims to analyze and compare heart rate peaks in preadolescent children throughout the day to track cardiac activity and identify potential abndormalities, that may be difficult to detect in brief medical examinations. Additionally, this study considers the growing prevalence use of computer games, particulary those with conflict-based and warlike themes, which warrant careful evaluation. Early findings suggest this aspect requires further investigation (Izzo R. et al., JPES, Oct.22). **Methods**: The examination was conducted with 12 subjects, whose average age was 10.3 ± 1.84 years, for a week. Data was collected using a state-of-the-art wearable device, a T-shirt (K-Sport Universal, Montelabbate, PU, Italy), which had sensors in smart textile capable of detecting heartbeats with medically certified accuracy. The device was also equipped with the K-AI position detector, which integrated 4 satellite tracking systems and 3 inertial sensors. The study focused on analyzing the impact of playing video games, watching TV shows, and engaging in sports, including football matches, on heart rate. **Results:** The examination was conducted with 12 subjects, whose average age was 10.3 ± 1.84 years, for a week. Data was collected using a state-of-the-art wearable device, a T-shirt (K-Sport Universal, Montelabbate, PU, Italy), which had sensors in smart textile capable of detecting heartbeats with medically certified accuracy. The device was also equipped with the K-AI position detector, which integrated 4 satellite tracking systems and 3 inertial sensors. **Conclusions:** The results suggest that heart rate performance of kids during everyday activities may have been underestimated previously and, therefore, it would be useful to conduct a deeper investigation of the values described above to determine the boundary between less regular trends. This could help provide preventive and health-related information on the daily use of video games, highlighting alert moments such as during school activities.
Keywords: obesity, kids, sleep, disorders, health, symptoms

Introduction

Although laboratory research on heart rate (HR) performance in 24 hours dates back to the 70's/80's (taking place in gyms and research centers), few studies have been conducted on the subject to date. In 1980, Scott et al. performed the first electrocardiography (ECG) investigation on healthy subjects aged between 10 and 13 years old over two consecutive days, observing their HR in different positions and during daily activities. While the maximum HR (HRmax) range was between 100 and 200 beats per minute (bpm), it corresponded to the waking period in general and not specific moments such as physical activity. In fact, a value of 200 bpm was recorded only in a patient with tachycardia. Studies on maximum test protocols to the cycloergometer (Kretschmann, 2014) or shuttle-run test on 20 meters (Szakály, et al., 2016) on a population of 10-12 years old revealed similar data regarding the HRmax, which was on average around the values of 202 ± 7 bpm. However, these studies also found peaks of 240 bpm (Kretschmann, 2014).

Unfortunately, there are few studies on this age group, and the accuracy of existing reports is questionable due to the instruments used in field applications. While books on sports physiology suggest that the HRmax of kids under 10 years old can "often exceed 210 bpm" (Kenney, et al., 2022), this claim is not well corroborated. This is because the determination of maximum heart rate (HRmax) in kids is a complex task, as subjecting them to maximum tests that could not only be dangerous, but also lethal to their health, can be

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considered both ethically infeasible and difficult to perform. As a result, some authors (Myrum et al., 2012; Rauber et al., 2018), pediatricians, cardiologists, and sports medicine doctors have resorted to calculating the theoretical HRmax using the same predictive formulas used for adults. The most commonly formulas are those of Cooper: HRmax = 220 - age (in years), and Tanaka: HRmax = 208- 0,7 * age (in years). However, differences in body size and physiological parameters between kids and adults suggest that it may not be entirely appropriate to extrapolate the predictive formulas utilized in adults to youngsters (Scott et al., 1980).

Moreover, 24-hour the monitoring of ìheart rate and cardiac path is a valuable tool to detect cardiac problems such as tachycardia, which is one of the primary causes of cardiac-related controls and hospitalizations in kids (Bieganowska et al., 2020). This monitoring is similar to that of a cardiac Holter and can identify potential cardiac issues at any time of the day. It is not always possible to detect cardiac problems during other screening visits, such as medical examinations or sports medical examinations lasting 30-40 minutes, which are performed in "protected" environments and not in conditions of free activity. Bieganowska et al. (2020), for example, found a considerable number of pediatric patients with asymptomatic cardiac arrhythmia without documented histories of previous palpitations.

Another field of interest that leads to the 24-hour monitoring of kids's cardiac health is the increasing concern due to the rise in obesity rates. Kids are leading sedentary lifestyles and spending excessive amounts of time engaging in recreational screen time. The emotional pressures they face due to the interactions and relationship with parents, social life, school, and academic performance further exacerbate the issue. Physical activity plays a crucial role in maintaining good health, but it is becoming increasingly infrequent among kids. (Rauber, et al., 2018). Unfortunately, only a small percentage of them fall under the general guidelines for physical activity (Majaj, et al., 2021; Szakály, et al., 2016; Dahlgren, et al., 2021). The World Health Organization (WHO) recommends that kids and adolescents between 5 and 17 years old engage in at least 60 minutes of moderate to vigorous activity per day while limiting sedentary activities, especially screen time during leisure.The spread of video games (especially of some kinds), and the popularity of TV - but not only - certainly does not help and leads that of childhood obesity to be a global problem (Rauber, et al., 2018; Dahlgren, et al., 2021). In fact, according to the WHO surveys, the rate of obese or overweight kids around 10 years is growing. This is an alarming signal considering the health risks related to them, such as cardiovascular diseases, diabetes, musculoskeletal disorders and certain types of cancer. In Italy, according to the latest national survey Okkio alla SALUTE (surveillance system on overweight and obesity and related risk factors in primary school children from 6 to 10 years), 20.3% of kids hadn’t performed any physical activity the day before the survey, 43.5% still have a TV in their bedroom and almost half of the kids spend more than 2 hours a day in front of TV/Tablet/Mobile. It is worth emphasizing that there are still no results from the period of the pandemic that surely did not reduce the problem.

Physical activity acts in all three stages of prevention (primary, secondary, tertiary), thus helping to maintain a good state of health or reducing any pathology symptoms. It is for this reason that there has been an increasing interest among some scholars in investigating the range of activities undertaken by kids to better comprehend their effects on the body and assess viable intervention strategies. This encompasses both conventional video games and the emergent active video games or exergames. According to Uber et al. (2018), active video games have the potential of increasing energy expenditure, physical activity levels, and enhancing health-related markers. However, it is noteworthy that their effectiveness is not as pronounced as that of traditional games, and they cannot substitute actual physical activity (Duncan et al., 2011), but they’re consistently better than doing activities like watching television, during which one stays sit down and still. Nonetheless, active video games can be deemed as a feasible alternative to elevate physical activity levels among kids and enable them to attain the recommended 60 minutes of physical activity per day as stipulated in the guidelines (Majaj et al., 2021). Even traditional video games are able to significantly increase multiple metabolic and physiological variables such as: HR, systolic and diastolic pressure, ventilation, respiratory rate, oxygen consumption and energy cost. This is why, according to Wang and Perry (2006), they should not be considered as watching TV in the assessment of sedentary life. At the same time, however, they cannot be a substitute for regular physical activity, which significantly stimulates the metabolic pathways necessary for cardiovascular conditioning. What is certain, however, is that video games create a stressful situation as they cause an increase in sympathetic activity and a decrease in HRV (Maia, et al., 2020).

Stress that has been seen to be associated with depressive symptoms, behavioral problems, anxiety, hyperactivity, inattention and sleep disturbances (Guerrero, et al., 2019). This risk strongly increased during the pandemic from Covid-19 due to the exaggerated growth in time spent in front of screens (Nagata, et al., 2020). At the behavioral level, the excessive use of video games is a phenomenon that is being more and more studied due to the fact that it can potentially lead to addiction. In fact, the term "Internet Gaming Disorder" in the fifth edition of the 'Diagnostic and Statistical Manual of Mental Disorders' (DSM-5) is to describe this phenomenon. However, it is important to note that there are still not enough studies to establish a definitive diagnosis. It should be remembered that in order to consider an activity as a behavioral dependence, we must take into account not only the amount of time spent on it but also the degree to which it leads to estrangement from social life (Nogueira, et al., 2019).Other researchers have also focused on the content of violent video games, their potential links to violent behavior (Ivarsson, et al., 2008). other than the bad influence on the sleep-health (Ivarsson, et al., 2013). These factors, combined with other underlying mechanisms, contribute to an increase in sleep disorders among young people nowadays.There are various factors that can affect sleep when using screens: the exposure to the bright light of screens, which suppresses the secretion of melatonin after prolonged use exceeding one hour (Hale & Guan, 2015) ; the involvement in spending a lot of time looking at a screen, whether it's for watching TV or playing video games that often causes people to lose track of time and delay their sleeping time, in conditions of being in of greater excitement, which significantly affects the dynamics of sleep itself ; the phenomenon of addiction associated with video games which leads to an increase in the level of attention or arousal that is stimulated by active participation in the game, as opposed to passively watching TV and the state of flow that players may experience when there is a proper balance between the level of challenge presented by the game and their own abilities. (Smith et al. 2017).

All mechanisms that can, voluntarily or involuntarily, delay the onset of rest, interfere with its cycles' architecture and reduce its quantity and quality (Candidate, et al., 2015; Guerrero, et al., 2019; Nagata, et al., 2020; Higuchi, et al., 2005; Brambilla, et al., 2017; Weaver, et al., 2010; Ivarsson, et al., 2013; King, et al., 2013). It is not a coincidence that teenagers more and more report a feeling of increased tiredness or bad rest during the night (Hale & Guan, 2015). It all boils down to learning, attention, and memory, which can influence academic achievement. This can also affect the mental health, with symptoms such as depression; the physical health, due to an augmented risk of being overweight and more, and on the emotional states and behavior (Montanari, 2017; Candidate, et al., 2015; Ivarsson, et al., 2008), creating a vicious circle with the problems described above. Vice-versa, "there is a strong association between the raise of sleep duration and the reduction of problematic behaviors" (Guerrero, et al., 2019). On the other hand, it is challenging to determine the exact causes and correlations underlying sleep disorders associated with screen time due to the contradictory results reported by several studies. The heterogeneity of the studies regarding subjects examined, devices used (TV, mobile phone, PlayStation or more than one), data collection tools, type of activity (movies, internet, video games, etc.), duration of screen time (less than 1 hour to greater than 4 hours), and the time of exposure (before or after 8 PM or close to going to bed) all contribute to the inconsistency of the findings. For this reason, there is still not much clarity on the subject and studies are needed that pay more attention to all these variables, in order to better investigate the psychophysiological mechanisms and draw more useful and meaningful conclusions.

It is important to note that the tools used in previous studies have limited the data collection process.While thoracic heart rate monitors have been commonly used, being minimally invasive and affordable, they have their own limitations. With the exponential growth of technology, wearable systems have emerged that can obtain dynamic ECG even during rapid movements, with certified medical-health precision. This development represents a significant improvement over previous methods.The ECG measurements obtained from a cardiac holter in a laboratory setting are currently the most accurate, but they lack practicality for use during normal daily life, particularly when there is a high range of movement dynamics. Instruments such as Actiheart or PocketECG can be considered a middle ground between the accuracy of Holter monitoring and the convenience of a heart rate monitor. However, they always require physical connection wires. Many of these studies are conducted in laboratories, which provides a controlled environment but doesn't reflect the need for direct assessment in the field, especially in sports activities. Moreover, it can cause inconvenience to individuals being monitored.

Based on the data collected, this study has focused on three main topics: video games/TV, training/football matches, and free play. These topics have been compared to the existing literature on the subject. The aim of the study is to bring attention to certain habits that are often considered normal, but could be indicative of situations that require closer monitoring.

Means and methods

Goal

The goal is therefore to evaluate HRmax in pre-teen subjects, through a monitoring system based on wearable technology in some typical activities for the ages taken into account. The analyzed activities are three:
1) video games and TV viewing;
2) training and football matches;
3) free play.

The work is a pilot transversal study that will then compare the data obtained in the three items and compare the results with the literature on the subject.

Subjects

A total of twelve kids, aged between 6 and 13, from two Italian youth football clubs, A.S.D. K-Sport Montecchio and F.C. Forsempronese, volunteered to participate in a study conducted in May and June 2021. Among the 12 participants, 11 were males, including two goalkeepers, and one was a female player. The average age of the players was 10.3 ± 1.84 years. The maximum theoretical heart rate for the players was determined using the formulas of Tanaka and Cooper.

According to Tanaka's formula, the maximum heart rate is 208 - 0.7 times the age in years, which for the players is 208 - 0.7 x 10.3, equaling 200.8 bpm. According to Cooper's formula, the maximum heart rate is 220 - the age in years, which for the players is 220 - 10.3, equaling 209.7 bpm.
Before the study, the research protocol was presented to the parents of the kids who then signed a release form, in accordance with the code of ethics.

Procedure

The data collection has been made using the latest generation technologies produced by K-Sport Ita., aimed at monitoring various kinematic and vital parameters, such as: acceleration, speed, total distance spanned, distance spanned at certain speeds and accelerations, metabolic power, heart rate and estimated energy expenditure. The specifications of the instrumentation used are as follows:

- K-AI (rel. 2021): an electronic device with dimensions of 78x42x17mm and a weight of 61g. It is equipped with internal memory, Artificial Intelligence, and Sensor Fusion technology. It uses Integral GNSS satellite tracking, with four satellite systems (GPS, Glonass, Compass, Beidu), the latest generation of inertial sensors at 8000 Hz, and is set for study at 100Hz (as shown in Figure 1).
- K-Shirt - a t-shirt designed to fit like a sports top and equipped with Smart Textyle textile sensors that are certified in the medical field. These sensors can detect the heart rate in real time, without any invasive measures. The shirt also collects individual positioning and acceleration/deceleration data, as shown in Figure 2.
- "Logbook": useful to identify activities and analyze data in the next two steps;
- K-Fitness: a software to download, catalog, and then upload to the online database the files recorded by the electronic device;
- K-Sport Online: online platform synchronized with the used devices, which is able to analyze and compare the data of interest for this study.

All kids and parents were instructed on how to properly use the instrumentation (exemplified information). They were asked to wear the sensorized t-shirt, with the device K-AI (in a special inter-scapular pocket), to every training and football match and other activities mentioned during the 24 hours of each day(at least 1 hour in the morning, 1 hour in the afternoon and 1 hour in the evening, for a week). They also had to write a sort of daily diary with the help of their parents, where they wrote down in detail the activities carried out, the start and end hours of each of them and the emotions experienced during the use of the instrumentation. The information during football training, related to activities and other special events, was collected directly by the researchers' group detectors (ARGS) duly trained.

Figure 1. K-AI

Figure 2. Sensoride t-shirt

Data nalysis

1. The data taken into account for this thesis work are:

Heart rate while playing video games and watching television (TV). Only values with a speed of less than 6 km/h and an acceleration of 2 m/s2 were accepted, allowing small displacements but less than a mild walk in order not to divert the survey. This is because the project was conducted in the months of May and June and, especially the latter, with significantly high temperatures, so sometimes even the activities of video games or TV were carried out outdoors. No further distinctions were made regarding the type of video games, the devices used (computers, mobile phones, tablets, PlayStation) and TV programs.

2. Heart rate during workouts and football matches.
3. Heart rate during free play, regardless of the type of activity.

According to the limit set by the online platform, the maximum accepted heart rate is 250 bpm. Whereas, the minimum value, chosen autonomously, is 197 bpm. This is because, as per the Cooper formula, the theoretical HRmax of the subjects is around 209.7 bpm, while the Tanaka formula gives an average of 200.8 bpm. Considering both formulas, which have a difference of 8.9 bpm, the average of the theoretical maximum heart rates is around 205 bpm. In discussing HR, it is common to refer to a range of values, rather than a specific number. Consequently, we have deemed it appropriate to consider all values in proximity to the average of two theoretical HRmax values, which is 205 bpm. More precisely, it has been deemed that data with a maximum of 250 bpm and within 96% of 205 bpm (197 bpm) are of interest and accepted. This approach allows to maintain sufficient flexibility while ensuring the data analyzed is meaningful and informative. The focus of this study was on events that involved a heart rate equal or higher than 197 bpm. Additionally, statistical data was collected to facilitate a quantitative and comparative analysis of the three items. The data included the absolute and relative frequency of the event of interest, namely HR ≥ 197 bpm, as well as the mean and standard deviation. To ensure medical accuracy, consultations were conducted with pediatricians and sports doctor (comment can be found further on).

Study Limitations

Despite having provided both parents and kids with information and instructions on the working protocol and use of materials, some individuals have not been paying sufficient attention and have not been performing the activity with precision. As a result, we had to delete certain files. It is evident that labor statistics are affected by this, especially considering the limited number of subjects examined and the data available. However, in order to ensure accuracy and scientific validity of the results, the insignificant data has been excluded, and future studies will improve upon this. Moreover, it is worth noting that there have been few instances where the specific video game played or television program watched was indicated. Unfortunately, we were unable to make a more specific and detailed distinction and analysis. Additionally, we had no information regarding food and drink intake. In certain situations, an excess of sugar could have contributed to a higher heart rate during quieter activities. Finally, although the kids reported that the sensorized shirt was comfortable and did not bother, the warm temperatures of June prevented them from wearing it during the night with the exception of three subjects. It would have been interesting proceed to further investigation on the effects of the different activities performed in the afternoon and their proximity to sleep during the night.

Results and discussions

Video games/TV

The video games/TV section includes playing on PlayStation4, playing with a tablet, watching TV, playing on a computer, and watching videos on a smartphone. There are a total of 46 files for each of these activities, but only 22 of them have recorded heart rate peaks greater than or equal to 197 bpm (HR ≥ 197 bpm), with a commonness of about 48%. Within the 22 significant files, the HR 197 bpm event manifests itself several times, but the table below shows only the highest figure for each individual activity. Table 1 displays the HR peaks broken down by individual subjects and activities: out of the 12 kids who participated in the test, only 9 have reported data regarding the use of video games or TV viewing, and only 6 of them have recorded HR values of 197 bpm or higher. It was observed that no heart rate peak occurred while watching videos on the phone or playing computer games. However, we don't have any specific information about the type of game played by the subjects, even though subject 1 reported playing on Playstation 4 while sitting on the sofa, as noted in their daily diary. Figure 3 displays the trend of HR, speed, and acceleration over time, while Figure 4 highlights the moment when the peak of 248 bpm was reached.

This is not an isolated case, and although there are no studies in the literature that have analyzed HR peaks in pre-teen kids, there are articles that attest to a significant increase in HR during and after the use of video games (Wang & Perry, 2006; Higuchi et al., 2005). Wang & Perry measured the average heart rate in the most active 3 minutes of video game play. However, their result of 116 ± 12.2 bpm is certainly much lower than what could be extrapolated in the plot of subject 1. For all the subjects who participated in the study, the television program they were watching at the time of the event is unknown too, except for subject 8. According to their report, subject 8 was watching a European Football Championship football match outdoors on the evening when they experienced a heart rate of 250 bpm. This information is confirmed by the time graph in Figure 5, which shows the acceleration and speed tracks. When a kid's heart rate reaches its peak of 250 bpm, as seen in Figure 6, the tracks become almost minimal.

This is mainly due to the emotional factor, which is caused by the opposing national team scoring a goal towards the end of the game, as well as other goal attempts by both teams. The Lahr index is commonly used to measure arousal, and an increase in the first leads to an increase in the second, resulting in greater active participation and involvement by the subject. In stressful situations, cardiac activity can increase, leading to a decrease in HRV that is disproportionate to current metabolic needs. This can occur in subjects who are not moving or are minimally active, as shown in studies conducted by Weaver et al. (2010), Maia et al. (2020), and Borusiak et al. (2008). It has been shown in studies that the increase in cardiovascular response only occurs when playing video games and not when watching TV.

Therefore, it is stressed that these two activities should be considered completely distinct due to the difference in their effects on the body (Wang & Perry, 2006). In contrast to them, during the study, the highest heart rate ever recorded during TV viewing or video games was 250 bpm.

Figure 3. Subject 1's heart rate, speed, and acceleration, during

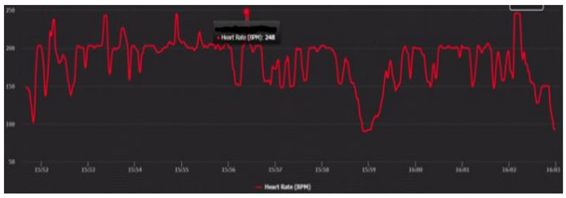

Figure 4. HR zoom of Figure 6 showing the peak of 248 bpm.

Table 1. Values of HR ≥ 197 bpm for the Video games/TV viewing section, classified by subject (ordinate axis) and activity (abscissa axis).

	PlayStation4					**Tablet Game**	**TV Viewing**				**Video on the Phone**	**Computer Game**
1	224	214	214	248	214							
2						224	203	213	214			
3												
4	218						231	211	226			
5												
6												
7							213	230	231			
8							220	231	198	250		
12							230	209				

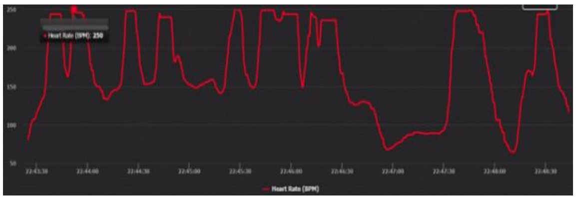

Figure 5. Graph of HR, speed and acceleration of subject 8 while watching a European Football Championship football match.

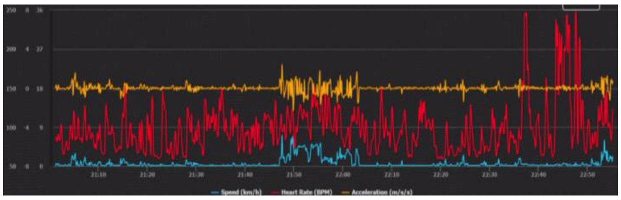

Figure 6. HR zoom of Figure 8 showing 250 bpm peak.

Training/football matches

The training/football matches section consists, as the name suggests, of both training and football matches. Every training session was divided and analyzed into three different parts: the warm-up, the central part, and the final part. The warm-up is generally characterized by free play or dynamic exercises in the form of play, while the central part focuses on technical exercises and/or small-sided games (SSG). The final part includes small games, SSGs, or penalties. The SSGs (Small-Sided Games) played in both the central and final parts of the matches were of different forms, such as 1vs1, 2vs2, 3vs2, 4vs3 (with a fixed goalkeeper), 5vs5, and 7vs7. The matches were played in three different time periods, known as T1, T2, and T3. In total, 41 files were recorded, consisting of 34 training sessions and 7 matches. Each file was analyzed at three different moments, making a total of 123 activities. Out of the 123 activities, only 51 of them reported values of HR (Heart Rate) at 197 bpm, with a frequency of approximately 41%. Out of the 51 files, the HR 197 bpm event was noted multiple times. However, only the highest data for each single activity has been reported in the tables below. Table 2 provides a breakdown of HR peaks by individual subjects and activities. The kids's data is available for all activities, as per the protocol, since the equipment was mandatory during the football workouts. Interestingly, HR values of 197 bpm were recorded in each kid. During penalty kicks and saves, the emotional state of an individual plays a crucial role. In these cases, the speed and acceleration were moderate or light, while in all other cases, the heart rate (HR) followed a peak of speed. The temporal graphs in Figures 7, 8, 9, and 10 reveal three elements: an acceleration of approximately 4 m/s2, a speed of 18 km/h or above, and a peak of HR shifted slightly more to the right than the peak of speed. This is a normal occurrence as the HR adjusts during exercise, with peripheral mechanisms detecting the demands of the organs involved in physical exertion and sending the information to the higher centers for regulation. Consequently, the peak of HR is slightly delayed compared to the peak speed.

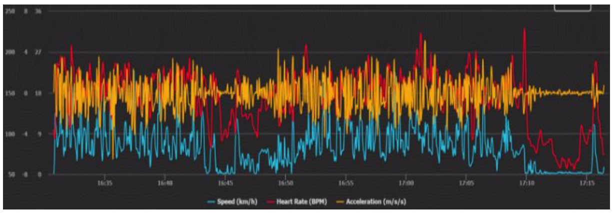

Figure 7. Chart of HR, momentum and acceleration of subject of 9 during a match

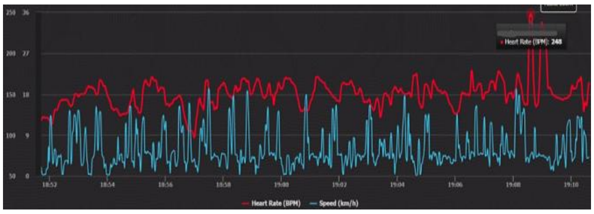

Figure 8. The HR zoom of Figure 10 didplays a peak of 248

It should be noted, however, that the elaboration of thought-movement by the central nervous system activates the centers of the autonomic nervous system and, in particular, of the sympathetic system that, through a release of catecholamines - especially adrenaline- will increase HR even before an individual actually starts to move; because just the idea to stand for, leads to this mechanism. As a consequence, before beginning an exercise, the body uses a central mechanism that affects the heart. Once the exercise starts and the muscles contract, a peripheral mechanism kicks in and adjusts to the actual needs of the muscles. According to Kenney et al. (2022), the adjustments made are directly proportional to the actual needs of the muscles. This means that the heart rate increases before the speed or acceleration track. It is worth noting that the heart rate is not a fixed value but oscillates; even during enduring intensity exercises, it takes 2 to 4 minutes for the heart to adjust and stabilize (Riebe et al., 2018). These aspects apply to all movement activities, including the free game section. The analysis of the data revealed that in some cases, the peak of the heart rate is accompanied by speeds smaller than those reported in the graphs below, but never less than 10 km/h. Additionally, the peak of the heart rate usually corresponds to emotionally charged situations, such as scoring a goal, having a goal scored by the opponents, saving a shot, or dribbling. As described in Figure 8 above, the highest HR value recorded during the training section/football matches was 248 bpm. This occurred in Subject 9 during a series of intense, amatorial match events, which included goals being conceded by the team, receiving the ball, dribbling between opponents, shooting, and saving.

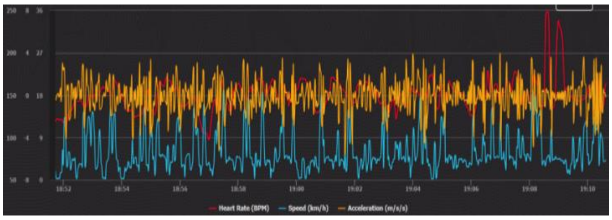

Figure 9. Chart oh the HR, speed and acceleration of subject 10

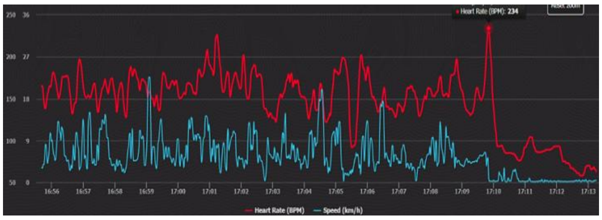

Figure 10. Zoom of Figure 10's HR showing the peak of 234 bpm

Table 2. HR 197 ≥ bpm values of the training section/football matches classified by subjects (abscissa axis) and activities (ordinate axis). SSG = Small-sided games (1vs1, 2vs2, 3vs2 and 4vs3 with fixed goalkeeper, 5vs5, 7vs7). Ex. Technique = Technical Tutorial.

	Warm-up			Football Match				SSG		Save		Technical Execution	T1	T2	T3	Penalty Kick
1	207			204				221				198				
2	204									219	201	204				
3	203	203		203	208	211	200	200	200			216	216	203	207	
4				208	214			207					214	214		
5	214															
6				208												
7	236	207	206	207											200	206
8	203															
9	205			248	199									206	208	
10	213	238		211				222				221			234	
11	234	205	207					207				204				
12				206												

Free play

The free play section of the study includes outdoor activities with friends such as hide and seek, football, volleyball, dodgeball, construction play, and other unspecified activities, as well as cycling and hanging out with friends. A total of 33 files were recorded, but only 21 of them reported peaks of heart rate (HR) of 197 bpm or higher, which is almost 64% of the total files. Within the 21 files, the HR ≥ 197 bpm event occurred multiple times. However, for the sake of simplicity, only the highest data for each individual activity has been reported in the tables below. Table 3 displays the HR peaks of the 12 kids who participated in the test, along with their corresponding activities. It should be noted that only 8 of the kids provided data regarding free play. While spending time with friends, there was no noticeable rise in heart rate. No significant changes in heart rate were observed while hanging out with friends. It is unclear what activities were engaged in, but it appears that no physical activity took place. The corresponding speed and acceleration analyses support this assumption. Figure 11, instead, displays a graph of a bike ride with friends, as evidenced by the speed track reaching between 30 and 36 km/h, followed by appropriate HR peaks. However, in the zoom of Figure 12, it is possible to see how the heart rate remains high for a few minutes, and it cannot be attributed solely to the speeds of the previous moments that reached a little more than 10 km/h. Emotional contribution must also be considered, but unfortunately, there is no information on that. Finally, in the rightmost part of the image, an isolated peak of 232 bpm is highlighted. It is located above and just before speed increases and then tends to remain more stable in a lower range. Although we have information about most of the activities that took place in the files labeled as "free game", as said at the beginning of this section, unfortunately, in the case shown in Figure 13, we do not. What we know is that subject 10 went to the park with friends the night after dinner.

From the graph in the figure, it can be deduced that the kid definitely ran, with mostly moderate speeds of below 10 km/h, but with two peaks between 15 and 20 km/h (clearly visible in Figure 14) followed by heart rate peaks. As a consequence of that, the high heart rate values can be explained by the analysis of the speed and acceleration, as well as the emotional involvement. However, it is not to be excluded that there may be other factors at play. It is noteworthy that one of these peaks is 233 bpm, which is the highest heart rate value ever observed in the free game section.

Table 3. HR ≥ 197 bpm values of the Free Play section classified by subjects (axis of the ordinates) and activities (axis of the ascisses)

	Free game outside with friends							**Bike with friends**		**Hanging out with friends**
2	221	223	222	220	222	202	208			
4	213									
6	214									
7	229									
9								226	222	
10	233							232		
11	203	214	212	214	204					
12	231	212								

Confrontation

After comparing the results obtained from three different activities (as shown in Table 4), it is evident that the highest heart rate recorded was 250 bpm, which was achieved while watching TV. However, it is important to note that 250 bpm is the upper limit set by the software, and it is not possible to determine if the heart rate would have been higher if the platform limit was set on a superior range. The heart rate of 248 bpm, recorded during football training and playing Playstation4, is also very high. The free play section recorded the lowest maximum heart rate of 233 bpm, which is different from the result of 216 bpm recorded by Szakàly et al. (2016) in a study that analyzed heart rate in children during various activities such as team sports, gymnastics, and athletics, carried out in physical education at school.

When we analyze the average of the peaks of heart rate, which is 197 bpm, we find that the video game/TV section is again in first place with 221 bpm, followed by 218 bpm of free play. This result is in contrast to the literature, which suggests that outdoor games and physical activity in general cause a greater cardiovascular response, leading to an increase in heart rate, not only when compared to TV but also to video games and active video games (Rauber et al., 2018; Wang & Perry, 2006). Finally, there are the training/football matches with 211 bpm. It is not surprising that children tend to play more during their leisure time than during organized activities.

This is because sports workouts involve many dead points and breaks, while children playing alone tend to have minimal breaks, if compared to the above-mentioned planned activities. Therefore it is during free play when kids tend to move more (Clemens & Lincoln 2018). According to what's just said, the majority of HR ≥ 197 bpm events occurred during the free game section, accounting for 64% of the total files. The video game/TV section had higher HR values than the training/football matches, positioning itself in the first place, the same as what happened with HR. It is worth noting that the total number of files is way higher for football workouts, compared to the other activities, due to the protocol requiring the use of instrumentation during all sessions. However, this result, despite being not obvious, it's not that relevant because it does not necessarily mean that kids played more football than other activities, as they may have played video games or engaged in outdoor activities without using the device.

Therefore, it is impossible to know if the total number of files matches the actual reality. This also applies to the comparison between the 33 files in the free game section and the 46 in the video games/TV section. The sedentary behavior of children is a growing concern, as documented by surveys conducted by the WHO, The Lancet, and other medical journals. These surveys show that not only do children spend too much time in front of electronic devices like TV, mobile phones, tablets, PlayStation, and computers, but they also fail to reach the minimum levels of physical activity recommended by current guidelines. Consequently, the rate of non-communicable diseases is increasing, particularly obesity and type II diabetes in children, as well as other issues related to behavioral, mood, and sleep disorders that are discussed in the introduction (p. 2-4).

Table 4. Comparison of the results of the three sections. HRmax = highest heart rate achieved; Average HR ≥ 197 bpm = average of HR ≥ 197 bpm values; SD = Standard Deviation; Events -total of files = number of files where the HR 197 bpm event occurred at least once, and the total of files; while Frequency of the Events = percentage of previous entries.

	Videogames/TV	**Trainings/Football games**	**Free play**	**Total**
HRmax	248/250	248	233 bpm	
Avarage HR ≥ 197 bpm	221	211	218	217
SD	± 12,62	± 10,82	± 9,21	
Events – total of files	22 su 46	51 su 123	21 su 33	94 su 202
Frequency of the events	48%	41%	64%	46,5%

Table 5, on the other hand, shows the values of HRmax and the average of the values of HR 197 bpm divided by subjects and items. According to some pediatricians who were consulted, the data shows that the highest limit for "physiological tachycardia due to stress, in this case physical," is 180 bpm. Scott et al. (1980) conducted a 24-hour electrocardiogram study on children between the ages of 10 and 13 and found that HRmax ranged between 100 and 200 bpm. Similarly, Szakály et al. (2016) measured HRmax in children aged 10-12 years through a 20-meter shuttle test and found that the result was 202.33 ± 6.82 bpm for males. However, it was reported by other sports physicians, who were asked for an opinion, that the classic theoretical formulas of Tanaka and Cooper were relied upon for the calculation of HRmax, which we also carried out in our study - as described above. The values of 200.8 bpm and 209.7 bpm obtained for HRmax were slightly higher, but still lower than many of the data obtained in this study.

Table 5. HRmax and Average HR ≥ 197 bpm data organized by subjects and items.

	Videogames/TV		**Trainings / Football games**		**Free Play**	
Subject	**HRmax**	**Avarage HR ≥ 197 bpm**	**HRmax**	**Avarage HR ≥ 197 bpm**	**HRmax**	**Avarage HR ≥ 197 bpm**
1	248	222,8	221	207,5		
2	224	213,5	219	207	223	216,85
3			216	205,83		
4	231	221,5	214	211,4	213	213
5			214	214		
6			208	208	214	214
7	213	224,66	236	210,33	229	229
8	250	224,75	203	203		
9			248	213,16	226	224
10			238	223,16	233	232,5
11			234	211,4	214	209,4
12	230	219,5	206	206	231	219,5

To provide more clarity and explanation for the results, we consulted with several medical experts, including pediatric cardiology. As previously mentioned, the maximum heart rate values accepted by the medical-scientific community (as per Tanaka and Cooper formulas) suggest that there could be two reasons behind our results:

1. Artifacts caused by movement
2. T wave oversensing

Wearable technology has the advantage of allowing long-term monitoring, which can be useful in identifying arrhythmia that may not be detectable by the ECG at rest or by the Holter. However, the various movements of the human body during daily activities can cause movement artifacts, which act as background noise and can interfere with the ECG's track, leading to inaccurate signal interpretation.

Also, chest malformations (such as sternal abnormalities, scoliosis, etc.) can produce abnormalities in the path. Although it is difficult to reduce motion artifacts because their manifestations are unpredictable, one study found that by integrating ECG signals with those of impedance pneumography, it is possible to significantly lower background noise (Xiang et al., 2022).

But then, oversensing of the T-wave is another very common phenomenon. It can happen that the QRS-T complex of the ECG goes out of the time range dictated by the specific algorithm of the device, causing a double count for each cardiac cycle. If this persists for several cycles, the heart rate track goes up and an alarm goes off indicating "tachycardia". In ICD (Implantable Cardioverter Defibrillator) patients, these tachycardic events can result in excessive rhythm or inappropriate shocks of the defibrillator, affecting the patients' quality of life. However, it is possible to solve the oversensing of the T wave by reprogramming some parameters of the device or by changing the filters for the detection of signals or, in the most complicated cases, by implanting a new device with an automatic sensitivity control (Rafle, et al., 2020; Johnson, 2010). Care must be taken, however, because over-processing/over-elaborating of signals can lead to further errors, such as removing or distorting potentially important information about heart electrical activity (Bear, et al., 2021)According to doctors, the comparison made with the inappropriate shocks of defibrillators helps to emphasize that the issue is not limited to the instrumentation used in this study, it is a problem that affects all types of instrumentation, even the most advanced ones used in hospitals. Each instrument has its own vulnerabilities and limitations. It has been acknowledged that there is a lack of information in the literature regarding heart rate (HR) in children, especially during exercise. To address this, it would be appropriate to compare the heart rate recorded by wearable technology and Holter monitor on the same individual in different positions (lying down, sitting up, standing up) to observe if the signal changes. Specifically, we could examine the complex QRS and T-wave ratios to understand if they are affected by changes in body position.ns. Moreover, they admit that there is little in the literature about HR in children and even less during exercise; for this reason, it would be appropriate to compare the heart rate of the Holter and wearable technology on the same subject in different positions (lying down, sitting up, standing up) to see if the signal or, more precisely, the complex QRS and T-wave ratio, changes as the position changes on its turn.

Conclusions and Future Possibilities

The aim of the present study was to investigate and compare heart rate peaks among preadolescent kids during different activities throughout the day, utilizing innovative instrumentation for data collection, such as wearable technology (e.g., K-Shirt from K-Sport Ita, a smart textile with electrocardiographic sensors validated at a medical level). Specifically, the study was focused on three activities: video games/TV, training/football matches, and free play. The rationale behind the study was to address the lack of information in the literature about maximum heart rate values in youngsters. It is not well-established how many times a child's heart beats per minute during a high-intensity exercise, especially concerning which activities cause more cardiac stress than others. Moreover, since nowadays, children are becoming more sedentary, spending extended periods sitting in front of electronic devices it has been deemed important to investigate how their heart rate behaves while playing video games or watching TV. I apologize for any confusion earlier. Here's the rewritten text, which includes all the substantive present in the original:

The results of the study revealed that during all three activities, the heart rate (HR) of the participants consistently exceeded the accepted HRmax value (210 bpm) among the medical population. Not only were values around 220 bpm recorded, which is not too far from the theoretical reference value, but there were also peaks around 230 bpm and even as high as 248 and 250 bpm. It is clear, therefore, that using the same formulas for calculating theoretical HRmax in children as in adults is not accurate, as children have anatomical and physiological differences, as it should be noted taking into account their differences, in order to obtain more precise results.

Otherwise, the cause would be abnormal tachycardia, which is certainly more difficult to detect during occasional screening visits but could occur during prolonged detection as in this study. If so, such results would be more than alarming considering not only the values achieved and the frequency with which they occurred, but also that they have been highlighted at least once in all the subjects examined. In addition, it has been seen that the free play section is the one that presents a higher percentage of events HR 197 bpm: the phenomenon is not surprising because it is known that in organized workouts, there are several moments of pause; while when children play freely they become more animated and reach higher intensities. Opposed to what one might expect, the data related to the video game/TV section for the HRmax peaks reached (the highest ever) as well as for the average HR of 197 bpm (which is higher than the other two items), and for the frequency in percentage of such events (which, although less free play, is higher than that of training/football matches) is both surprising and, at the same time, worrying. All this is accentuated by the difference in speed, which is nothing in the video game/TV section but never less than 10 km/h in the other two sections. HR values differ also from those reported in previous studies, probably due to the advances in technology that allow a more accurate collection of data in more realistic situations. Despite the high internal load achieved, as reported by the literature, the possibility of comparing the use of video games or the viewing of TV to purely motor activities is excluded, since metabolic processes are not affected in the same way. Undoubtedly, emotional involvement plays a significant role in these activities. However, as reported above, it would be important to monitor a group of subjects simultaneously using both Holter and wearable devices during the same activities and in different positions in order to verify the appearance of any possible artifacts caused by movement or oversensing of the T wave. Furthermore, with the hope of ruling out any potential pathological causes, it's important to determine the consequences of a cardiac load resulting from a sedentary lifestyle. Investigating the following aspects would be useful in this regard:

1) whether the high heart rate, resulting from the use of video games on the same day as football training, may make the heart's activity inadequately worse and put youngster's health at greater risk;
2) how heart rate behaves during sleep, when high values were reached during the day playing video games;
3) whether problems linked to excessive use of video games that repeatedly cause heartbeat peaks can arise in the long term (intensive and long-term screening).

As there are guidelines for the daily amount of physical activity and sedentariness, maybe it is the case to establish general recommendations to advise a maximum daily or weekly time of video games use, also by monitoring the types of games played, some of which present very engaging and challenging situations under the physiological and neurological aspects, and whether special attention should be paid to the days of moderate/intense physical activity. Undoubtedly, even this new step regarding such studies does not claim to be definitive, but it aims at providing and obtaining further elements to perfect the detection protocol of an innovative device that has overall responded very well to scientific expectations in terms of precision and easy wearability, being essential for this type of "field" research.

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Sitography

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