SUSTAINABILITY & SPORTS SCIENCE JOURNAL

ORIGINAL ARTICLE

Comparative analyses of implementation of connected sensors on heart rate variability in middle school judo athletes versus non-athletes

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ABSTRACT

Purpose: This study aimed to examine the differences in heart rate variability (HRV) between athlete and non-athlete students in middle school using unimplemented sensor heart rate. Materials and Methods: Sixty-seven judo athlete and non-judo-athlete students were recruited to the study from middle school were divided into experimental groups (n = 39, height 162.4 ± 7.6 cm, weight 52.7 ± 6.3 kg, Age 12.8 ± 1.3 years), and Control group student (n = 37, height 159.1 ± 6.9 cm, weight 53.2 ± 7.3 kg, age 13.2 ± 0.8 years),The CG students did not take part in any competitive sport at any level, Measure mean heart rate (Mean HR), mean R-R, standard deviation of all normal R-R intervals; (SDNN) and relative, root of the mean squared differences of successive RR intervals (RMSSD),low-frequency (LF), high-frequency (HF) and low-frequency ratio (LF/HF) indicators were used. The T-tests was used to compare sports teams with general differences between athlete and non-judo-athlete students. The significance level was set at $p < .05$. Results: HRV analysis software analyses the (RR) interval time domain components and the results were given as standard deviation of RR intervals (SDNN), square root of the mean of the sum of the squares of differences between adjacent RR intervals (RMSSD), adjacent RR interval differing more than 50ms (NN50), The Mean (iRR) of the EG is significantly higher than that of the average CG ($t = 2.245$, $p < .05$); in terms of Mean HR, the EG are significantly lower than the average CG ($t = -2.149$, $p < .05$). Conclusion: Judo training and combat field exercises utilising connected sensors are effective for middle-aged individuals, helping to maintain and reduce resting heart rate while enhancing cardiopulmonary function.
Keywords: Health, Judo, Combat field, Heart rate, Variability, Middle school.

Cite this article as:
Moussa, M., Belkadi, A., Benhammou, S., Dairi, A., & Benbernou, O. (2025). Comparative analyses of implementation of connected sensors on heart rate variability in middle school judo athletes versus non-athletes. *Sustainability and Sports Science Journal*, *3*(2), 112-124. https://doi.org/10.55860/WXUS7730

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Submitted for publication January 24, 2025.
Accepted for publication March 19, 2025.
Published March 25, 2025.
Sustainability and Sports Science Journal. ISSN 2990-2975.

Identifier: https://doi.org/10.55860/WXUS7730

INTRODUCTION

Variability in beat-by-beat heart period is an intrinsic characteristic of healthy cardiac functioning (Draghici & Taylor, 2016), (Vigo, Siri, & Cardinali, 2019) observed that the arterial pressure during the respiratory cycle and the time between heartbeats were variability. When the heart beats, it does not beat at a fixed speed, and there is a small gap within tens of milliseconds between a normal heartbeat and a heartbeat. several studies by (Freeman, Dewey, Hadley, Myers, & Froelicher, 2006; Fu & Levine, 2013; Hautala, Kiviniemi, & Tulppo, 2009; Iellamo, Volterrani, Di Gianfrancesco, Fossati, & Casasco, 2018) pointed out that although the heart beats regularly due to the discharge of the sinus node of the right atrium, the discharge of this sinus node is affected by the autonomic nervous system. The sympathetic nervous system accelerates the discharge rate of the sinus node, thereby increasing the heart rate (Zhou et al., 2016). The parasympathetic nervous system inhibits the discharge rate of the sinus node, and the heart rate slows down (Sztajzel, 2004). Due to the difference between the sympathetic nervous system and the parasympathetic nervous system (Hinojosa-Laborde, Chapa, Lange, & Haywood, 1999; Rowe & Troen, 1980) Mutual antagonism causes the frequency of sinoatrial node discharge to be differently regulated by the autonomic nervous system (Rocchetti, Malfatto, Lombardi, & Zaza, 2000), which makes the heart beat show different degrees of variability called heart rate variability (HRV) (Lehrer & Gevirtz, 2014; Shaffer & Ginsberg, 2017). Heart rate variability can be analysed by electrocardiogram. On the electrocardiogram, the R wave is a more significant waveform that is easy to be detected (Bansal, Khan, & Salhan, 2009; Selvaraj, Jaryal, Santhosh, Deepak, & Anand, 2008). The R interval represents the rate of the heartbeat. Therefore, the RR interval (RRI) is most often used to represent the heartbeat interval (such as Figure 1). Heart rate variability analysis can be divided into time domain analysis and frequency domain analysis (Kuss, Schumann, Kluttig, Greiser, & Haerting, 2008).

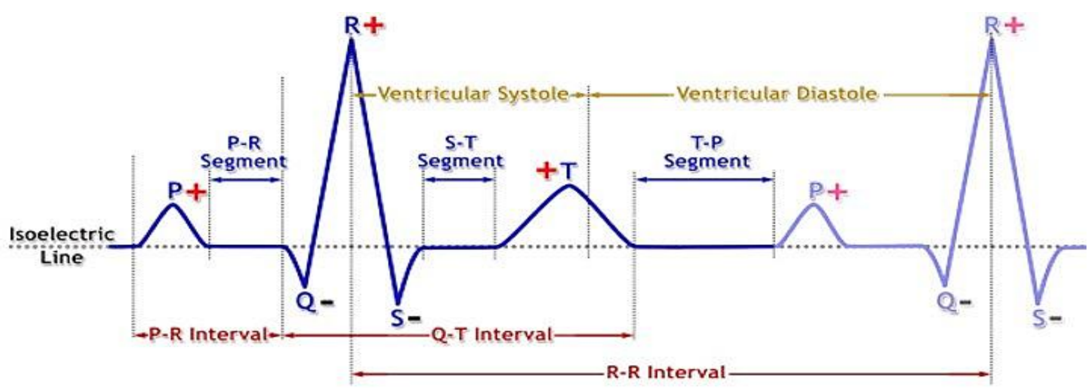

Figure 1. The interval between adjacent R waves is RR interval (RRI).

Early heart rate variability analysis is mostly used in clinical medicine, and the autonomic nerve control mechanism can be used to obtain evaluation data from this analysis. Various parameters of heart rate variability can be used to determine the pros and cons of heart function. A study by Yan Wang and Jun Xu (Yan, Jun, & Guo-Rong, 2006) pointed out that changes in some parameters of heart rate variability can be used as reference indicators for judging the severity and prognosis of patients with chronic heart failure. Cannon Christopher (Cannon et al., 2001) believe that the continuous measurement of heart rate variability should be regarded as indispensable in the care after complete coronary artery bypass surgery.

In addition to clinical medicine, heart rate variability has also been widely used in sports science research in recent years. In addition to explore the impact of exercise training on heart rate variability, heart rate variability it was often used to test the effectiveness of sports training (Sandercock, Bromley, & Brodie, 2005). Aubert et al., (2003) noted that the heart rate variability is used to evaluate the impact of different pace methods on sports performance (Manar, Adel, Lalia, & Saddak, 2023). The application of heart rate variability in sports is mainly to evaluate the activity of the autonomic nervous system (sympathetic and parasympathetic nerve) through various indicators to measure the effect of sports training or sports performance. The increase in sympathetic activity is conducive to coping with emergencies; the activity of parasympathetic nerves is better, for sports that require high concentration, it is conducive to achieving better results, and at the same time, it can recover faster after exercise (Makivić, Nikić Djordjević, & Willis, 2013). Many studies have shown that exercise has the effect of improving heart rate variability (Borresen & Lambert, 2008; Lehrer & Gevirtz, 2014; Sandercock et al., 2005; Wheat & Larkin, 2010). Makivić et al (Makivić et al., 2013) pointed out that the index of heart rate variability is helpful for sports performance and anxiety control during competition. (Tang et al., 2009) stated that the analysis of heart rate variability of gymnastics students in sitting, resting and inverted upside down showed that they have better autonomic nervous system regulation. (Aubert et al., 2003) mentioned that the heart rate variability of non-athletes is lower than that of athletes (Belkadi, Alia, & Mohammed, 2020).

Exercise can improve the activity of the heart's autonomic nervous system. If engaged in long-term, high-intensity or endurance sports training, it can increase heart rate variability and reduce the risk of cardiovascular disease (Boudehri, Belkadi, Dahoune, & Atallah, 2023); There is no significant difference in short-term and medium-intensity sports training. Regarding the effect of long-term exercise training on heart rate variability in the past, (Cherara, Belkadi, Mesaliti, & Beboucha, 2022) pointed out that they have been engaged in exercise training for a long time. Elderly males aged 13 to 15 years have better vague nerve and sympathy Nerve control ability. (Deus et al., 2019) Aimed at average practice Middle-aged and elderly people who practiced 3 times a week for at least 1 hour each time and the general group of the same age conducted research. The results pointed out that the short-term effect of (Adel et al., 2019) on middle-aged and elderly people is to reduce their sympathetic nerve activity and increase their parasympathetic nerve activity; The long-term effect is to enhance sympathetic nerve activity without affecting parasympathetic nerve activity. (Romanchuk & Dolgier, 2021) explored the effects of prolonged aerobic exercise on middle-aged women. The results of the study showed that continuous aerobic exercise for 3-5 years, 3 times a week, can increase sympathetic nerve activity and reduce their parasympathetic nerve activity.

Regarding the impact of short-term exercise training in the past on heart rate variability, after 8 weeks of shooting training, (Thayer, Hansen, Saus-Rose, & Johnsen, 2009) showed significant relationship among cognitive performance, HRV, and prefrontal neural function that has important implications for both physical and mental health. However, some studies believe that exercise cannot change heart rate variability. Ladawan et al., (2017) pointed out that 12 weeks of mid-intensity aerobic exercise improved attention, brain processing speed, blood pressure and maximal workload in healthy middle-aged subjects. (Jurca, Church, Morss, Jordan, & Earnest, 2004) discussed the effects of 8-week aerobic exercise intervention on cardiorespiratory endurance and heart rate variability (Benhammou et al., 2022). The results also showed that short-term, medium-intensity segmented exercise training had the same effect as continuous exercise training, but none Method to improve the heart rate variability of college students. (Del Rosso, Nakamura, & Boullosa, 2017; Hautala et al., 2003) showed that after anaerobic high-intensity exercise, the parasympathetic nerve activity of football players was lower than that of college physical education students, and there was no difference between the two after aerobic exercise (Beboucha, Belkadi, Benchehida, & Bengoua, 2021). Most of the early applications and researches on heart rate variability have appeared in the clinical medicine of middle-aged and elderly people. In recent years, the instruments have become more advanced, easy to operate and easy to obtain, which makes scholars more willing to turn the research objects to young children. (Yeh & Kuo, 2012) studied the influence of Wii Sports sports mode on energy expenditure and heart rate variability of elementary and elementary school children. Among them, the index of heart rate variability of boxing is significantly higher than that of baseball and tennis. (Kraama, 2013) carried out 8-week cycling and aerobic training for 13 to 15-year-old children. The results of the study indicated that these physical training had no significant effect on heart rate variability. (Gamelin et al., 2009) performed 7 weeks of high-intensity interval exercise training on 38 children aged 8 to 11, and found that there was no significant difference in the heart rate variability indicators between the sports team group and the general school child group (Belkadi et al., 2015). The above studies are all aimed at children in elementary and middle schools, observing the effect of exercise intervention on heart rate variability. In view of the fact that training is essentially a physical and mental exercise stimulation, Based on the existing literature, the training time of less than 8 weeks seems to be too short to cause adaptation. (Cornelissen, Verheyden, Aubert, & Fagard, 2010; Gamelin et al., 2009; Jurca et al., 2004; Kraama, 2013), the effects of exercise on HRV are mostly insignificant, and the results of many studies are not consistent; Training intervention seems to have a more significant impact on HRV (Jurca et al., 2004; Romanchuk & Dolgier, 2021; Scheer, Siebrant, Brown, Shaw, & Shaw, 2014). Therefore, this study aims to clarify the influence of heart rate variability between the middle school team players and ordinary school children engaged in long-term sports training, in order to provide reference for sports trainers during the sports Saison.

MATERIAL AND METHODS

Study group

Seventy-six athlete and non-athlete students were recruited for the study from middle school and were divided into two groups: the experimental group (EG) consisting of 39 athletes (height 162.4 ± 7.6 cm, weight 52.7 ± 6.3 kg, age 12.8 ± 1.3 years) and the control group (CG) comprising 37 non-athletes (height 159.1 ± 6.9 cm, weight 53.2 ± 7.3 kg, age 13.2 ± 0.8 years). The EG students participated in a wide range of competitive sports at various levels, including football, athletics, swimming, martial arts, and handball. They had received sports training for more than six months, engaging in 90 minutes of basic physical fitness and sports training from Sunday to Wednesday. In contrast, the CG students did not participate in any competitive sports at any level.

Before the experiment, the protocol was explained to the participants and their parents or legal guardians. They were asked to fill out the "*Subject and Parents Consent Form*" and the "*Subject's Basic Information and Health Status Questionnaire*".

Procedure/Test protocol

Before conducting the study, it was stated in the consent form signed by the subjects and their parents that "*the subjects should not eat any irritating food, such as tea, coffee, etc., the night before, and keep their mood stable*.", and invite the subjects to enter the test Do not talk to people after the location to avoid affecting the heart rate variability data obtained in the experiment. Before the test, the subjects lie down for 10 minutes before testing and then put on a pulse sensor (Pulse sensor, World Famous Electronics llc., USA) on the left middle finger. The application Processing-3.3 monitors the heartbeat and then opens the application arduino-1.8.0-windows to collect 10 minutes of ECG data, with a sampling frequency of 100 times per second (Figure 2).

The ECG data collected by Arduino is compiled into Kubios HRV heart rate variability analysis software (Tarvainen, Niskanen, Lipponen, Ranta-Aho, & Karjalainen, 2014) through MATLAB R2015b to read the format, and then input the Kubios HRV program to generate heart rate variability data (e.g. Figure 3).

Figure 2. Heart rate variability measurement and signal acquisition.

Figure 3. Data generated by Kubios HRV heart rate variability analysis software.

The parameters of heart rate variability adopted in this research was carried similar to (Makivić et al., 2013).

Time domain analysis

The analysis method is to detect the interval of each QRS complex wave in the continuous ECG. The adjacent R waves represent the cycle of the heartbeat. This interval is the RR interval, and the continuous interval formed by the continuous RR interval is Represents the variability of heart rate (Sharma, Subramanian, Arunachalam, & Rajendran, 2015).

- Mean RRI: The average value of the heartbeat interval, an indicator of overall heart rate variability.
- SDNN: The standard deviation of the normal heartbeat interval, that is, the square root of the variance.
- Mean HR: The average number of heart beats per minute.
- RMSSD: The root mean square of the sum of squares of the difference between adjacent normal heartbeats.
- pNN50%: The ratio of the difference between adjacent normal heartbeats exceeding 50 milliseconds. The number of normal heartbeats with a difference of more than 50 milliseconds divided by the total number of heartbeat intervals.

Frequency domain analysis

The commonly used calculation method is fast Fourier transformation (FFT), which analyses the distribution of power (the variance) at various frequencies.

- Low frequency power (LF): The captured frequency is 0.04 ~ 0.15 Hz refers to the variation of the normal heartbeat interval in the low frequency range and represents the sympathetic nerve activity or the index of the simultaneous regulation of sympathetic nerve and parasympathetic nerve.
- High frequency power (HF): The captured frequency is 0.15 ~ 0.4 Hz refers to the variance of the normal heartbeat interval in the high frequency range and represents an indicator of parasympathetic nerve activity.
- Low and high frequency power ratio LF/HF: An indicator that reflects the balance of sympathetic and parasympathetic nerves or represents the condition of sympathetic nerve regulation.

Data collection and analysis

The data measured in the experiment are statistically analysed with SPSS 22.0, descriptive statistics present the basic data values of the subjects; independent sample t test analysis is used to compare whether the experimental group and the control group have significant differences in heart rate variability, and the significance level is $p < .05$ was considered.

RESULTS

The time domain analysis is shown in Table 1. The results show that the experimental group and the control group have significant differences in Mean iRR and Mean HR, while the other indicators are not significant. The Mean iRR of the elementary school sports team players is significantly higher than that of the average school children ($t = 2.245$, $p < .05$); in terms of Mean HR, the elementary school sports team players are significantly lower than the average school children ($t = -2.149$, $p < .05$). The results of frequency domain analysis are shown in Table 2. The results show that there is no significant difference between the two groups in the low frequency (LF), high frequency (HF), and low frequency/high frequency (LF/HF) indicators.

Table 1. Comparison of time domain analysis of heart rate variability between experimental group and control group.

	Experimental group (n = 39)		**Control group (n = 37)**		***t* Value**	**Obs.**
	M	SD	M	SD		
Mean RRI(ms)	805.12	4	746.64	81.65	2.245*	Experimental＞Control
SDNN(ms)	95.82	38.22	91.40	43.96	.491	
Mean HR	78.55	9.57	82.95	9.03	-2.149*	Control＞Experimental
RMSSD (ms)	86.75	42.70	84.47	46.90	.232	
pNN50(%)	31.19	19.90	30.256	17.76	.223	

*Note. *p < .05.*

Table 2. Comparison of the time domain analysis of heart rate variability between the experimental group and the control group.

	Experimental group (n = 39)		**Control group (n = 37)**		***t Value***
	M	SD	M	SD	
LF	2790.93	3415.44	3887.80	6227.54	***-1.010***
HF	2419.00	2483.05	3153.83	3502.45	***-1.112***
LF/HF	***1.30***	***0.70***	***1.13***	***0.72***	***1.081***

*Note. *p < .05.*

DISCUSSION

From the results of this study, it is found that the Mean RRI and Mean HR of the upper-grade students in elementary school after more than half a year of exercise training are significantly better than those of the untrained students; other time-domain analysis indicators SDNN, RMSSD, and pNN50 are between the two groups Although there is no significant difference, there is a trend that the experimental group is better than the control group. Both the longer Mean RRI and the lower Mean HR show that the trained children have better cardiorespiratory fitness. This result is consistent with many previous studies. The research results of (Draghici & Taylor, 2016; Iellamo et al., 2018; Levy et al., 1998; Sztajzel, 2004) point out that whether it is explosive or the average heart rate of endurance athletes was significantly higher than that of the control group, and the average heart rate of both athletes was significantly lower than that of non-athletes, especially for endurance athletes. Athletes have the lowest heart rate. This result is also consistent with the results of (Aubert et al., 2003; Buchheit, Simon, Piquard, Ehrhart, & Brandenberger, 2004; Deus et al., 2019; Romanchuk & Dolgier, 2021) showing that exercise can produce a quiet heartbeat slowdown. In addition, this study found that the other time domain indicators (SDNN, RMSSD, pNN50) of the sports team group tended to be better than those of the general schoolchild group. RMSSD and pNN50 have a high correlation (Vanderlei, Silva, Pastre, Azevedo, & Godoy, 2008), which is used to estimate the function of the parasympathetic nerve and show the movement. The parasympathetic nerve function of the representative team group tends to be better than that of the general school children group. Based on the results of the frequency domain analysis of this study, the three indicators of LH, HF and LF/HF did not reach significant differences between the experimental group and the control group. Judging from a number of previous papers on heart rate variability with healthy school children as subjects (Gamelin et al., 2009; Hautala et al., 2003; Joyner, Charkoudian, & Wallin, 2008; Kraama, 2013), exercise training has no significant effect on the frequency domain analysis indicators of school children. The results of this study are roughly in line with these documents. Mandigout et al., (Mandigout et al., 2002) targeted 19 children aged 10-11 For 13 weeks of running endurance training, in the frequency domain analysis of the sports team group, there is no significant difference between LF and HF and the general schoolchild group. The researchers believe that endurance training has a positive effect on the aerobic capacity of healthy pre-adolescent children (Bansal et al., 2009; Kraama, 2013), but Will not cause changes in sympathetic and parasympathetic nerves. The results of (Del Rosso et al., 2017; Hautala et al., 2003) showed that after anaerobic high-intensity exercise, the parasympathetic nerve activity of football players was lower than that of college physical education students (Saddek et al., 2020; Senouci, Asli, Belkadi, Bouhella, & Koutchouk, 2024), which involved short high-intensity activities stressing both aerobic and anaerobic metabolic pathways.

There is no difference in regulation. Sacknoff, Gleim, Stachenfeld, and Coplan (Sacknoff, Gleim, Stachenfeld, & Coplan, 1994) studied 12 athletes and 18 non-athletes and found that the time domain of athletes' heart rate variability is greater than that of non-athletes, while the total energy and high-frequency power are less than non-athletes. Observed in non-athletes; The correlation between time domain and frequency domain is not observed in athletes, because This researcher believes that the index of heart rate variability in the frequency domain cannot accurately assess the activity of the parasympathetic nerve of the athlete's heart. Oliveira, Barker, Wilkinson, Abbott, and Williams (Manar et al., 2023; Oliveira, Barker, Wilkinson, Abbott, & Williams, 2017) conducted a systematic and comprehensive analysis of relevant literature to explore the relationship between HRV, physical activity, and cardiopulmonary function in children and adolescents.

Correlation between indicators of frequency domain analysis

The results of the above-mentioned literature on heart rate variability of school children are mostly consistent with the results of this study, but there are also some research results that show that exercise intervention can significantly increase the heart rate variability. There are many literatures on the significant heart rate variability of adults after interventional exercises, especially many studies on middle-aged and elderly people or patients with heart disease as subjects (Belkadi et al., 2025; Benchehida et al., 2021; Yacine et al., 2020). After long-term exercise training, regardless of the type of exercise training, aerobic exercise or resistance exercise seems to have resulted in an increase in HRV (Romanchuk & Dolgier, 2021; Selig et al., 2004; Ueno & Moritani, 2003). This study is mainly aimed at children.

The insignificant reason may be that the heart rate variability of the children in the growth stage has not matured, although the control group has not exercised a long Training, but individual growth factors also have an effect on heart rate variability. Therefore, the heart rate variability changes of children's long-term exercise training are affected by age factors and are not easy to reach significant differences. Wu Rongzhou et al. (Rongzhou, 2011) conducted heart rate variability analysis on 750 healthy children, and found that regardless of the time domain analysis of SDNN, SDANN, PNNSO, RMSSD or the frequency domain analysis of TF, VLF, LF, HF, LF/HF and other indicators, There is a significant increase with age. It can be seen from previous related studies that the age-dependent changes in HRV may be related to the maturation process of the autonomic nervous system, and also to the increase in heart volume from infancy to adulthood (Benhammou, Mourot, Clemente, Coquart, & Belkadi, 2024; Kraama, 2013).

CONCLUSION

The conclusion of this study is that the quiet heart rate of regular training students in the upper grades of elementary school tug-of-war and the athletics team is significantly lower than that of ordinary school children. This shows that regular training or exercise can promote cardiorespiratory fitness. Parents and teachers should continue to promote and encourage school children to participate Sports. Compared with sports, the stimulation of growth and development is more likely to be an important factor affecting the HRV changes of school-age children. This may be the main reason for the small difference between the HRV of the sports team in this study and the general birth. The individual growth factors of elementary school children in China also have a considerable impact on the heart rate variability, so the heart rate variability involved in sports training is not likely to change significantly. This factor may be a limitation of this type of related research. In addition, although the subjects in this study are all children who have received sports training for more than half a year, there are still differences in training courses.

AUTHOR CONTRIBUTIONS

Moussa Mohammed: study design, data collection, data analysis, and manuscript preparation. Belkadi Adel: study design, data analysis, and manuscript preparation. Saddek Benhammou: data collection, data analysis. Abdelkader Dairi: study design, data analysis. Otmane Benbernou: data analysis, and manuscript preparation.

SUPPORTING AGENCIES

We thank The Thematic Agency for Research in Social and Human Sciences (TARSHS) and Training-University Research Projects (PRFU N° J00L02UN270120230001, Agreement: January 2023) for their cooperation and support in setting up the study. We also acknowledge their role in maintaining financial support and ensuring the quality of research.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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