INTERRELATION BETWEEN HEART RATE AND MENTAL WORK AFTER PHYSICAL LOAD

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ABSTRACT

The attitude towards the functional activity of the heart has been changing recently. While contracting the heart is supposed not only to guarantee bloodstream circulation but also to send nervous, hormonal and electromagnetic information, to interrelate the body, the mind, emotions and spirit (Lacey J., Lacey B., 1978; Armor, Ardel, 1994; Goleman, 1995; Childre, Martin, 1999). It was found that the heart rate and its variability sensitively responded to the mental load (Hjortskov et al., 2004; Wand et al., 2005). The changes in the heart during and after the physical load is a question of detailed discussion in literature, but there are few studies on the changes in the heart rate during mental work after the physical load has been applied.

The aim of research was to establish the links between the changes in the heart rate variability and the level of mental working capacity after standardized physical load of athletic and non-athletic females. Ten athletic and eight non-athletic females participated in the research. The mean age of the research participants was 23. The study was carried out in the "Center for Research of Human Physical Abilities" at the Lithuanian Academy of Physical Education in 2003. During the research the data were registered as a continuous electrocardiogram with RR intervals, using a special computer program (Vainoras, 2002). We analyzed the indicators of the heart rate and its variability: the median of heart RR intervals in ms; standard heart RR intervals variability in ms — RR dispersion, ms; the percentage of standard heart rate variability — RR dispersion, %; heart rate variability RRj after comparing the duration of heart cycles in ms — RR (j + 1) dispersion, ms; heart rate variability δ (RRj) after comparing the duration of heart cycles in percent — RR (j + 1) dispersion, %. The research participants performed a mental work test before and after the standardized physical load (150 W) (Grinienė, Vaitkevičius, 1998). We considered the following mental work parameters: work intensity (the number of reviewed signs), accuracy of work (the number of mistakes) and the efficiency coefficient Q which was estimated using the formula $Q = (i / 10)^2 / (i / 10) + a$*, where i — the number of reviewed signs, a — the number of mistakes.*

Results. It was found that the indicators of the heart rate and its variability in both groups before the physical load were similar. The mental work indicators before the physical load in both groups were similar too because the work was of the same intensity and accuracy. After the physical load athletic females recovered their usual heart rate and its variability sooner compared to non-athletic females (p < 0.05), their mental work indicators were significantly higher while the indicators of the mental in the group of non-athletic females remained unaltered. The results of the research revealed that athletic females possessed better functional activity of the heart after the physical load which favorably affected their mental work. The lower functional activity of the heart in the group of non-athletic females affected their performance in the test of mental work.

Keywords: *heart rate variability, physical load, mental work test.*

INTRODUCTION

The attitude towards the functional activity of the heart has been changing recently. While contracting the heart is supposed not only to guarantee bloodstream circulation but also to send nervous, hormonal and electromagnetic information, to interrelate the body, the mind, emotions and spirit (Lacey J., Lacey B., 1978; Armor, Ardel, 1994; Goleman, 1995; Childre, Martin, 1999). It was found that the heart rate and its variability sensitively responded to the mental load (Hjortskov et al., 2004; Wand et al., 2005). The changes in the heart during and after the physical load is a question of detailed discussion in literature, but there are few studies on the changes in the heart rate during the mental work after the physical load has been applied. The continuous recording of the electric processes of the heart for a longer period of time (an hour, day and night) provided an opportunity for the evaluation of the variability of the heart rate and other parameters, as well as their changes applying different physical activity (Zemaityte, 1979; Ursino, 1998; Malik, Comm, 2000). The records of RR intervals revealed the role of the heart rate variability in the chain of the body's adaptation to physical exercises as well as the interaction between physiological processes of mental activity, emotions and different behavior (Childre, Martin, 1999). It was determined that the heart rate increase and the change of the variability of its activity are proportional to the intensity of the physical load; this depends on the initial state, the physical activity of an individual and associates with systematic and strenuous exercise (Victor et al., 1987; Davy et al., 1998; Sawai et al., 2005). During the physical load the heart rate variability is impacted by the functional state of the heart's automatic regulatory system, the nature of the tonic and reflex interaction between parasympathetic and sympathetic nervous systems which receive decisions of the central nervous system from its subordinate levels (Googvin, McCloskey, 1972; Mallani et al., 1991; Zemaityte, 1997). After the physical load the heart's chronotropic activity rapidly recovers the former state of rest. After high intensity physical loads it may occur either quickly or slowly (Savin et al., 1982; Victor et al., 1987; Singh et al., 2002).

The heart rate and its variability alter not only during the physical activity but during the mental activity as well. This is associated with the changes in the balance of arousal and suppression, mobility and power changes in the brain, the increased synchronization of alpha-wave activity and the heart rate cycles (McCraty et al., 1999). For this reason it is worth studying the function of the heart activity during the mental work. It was identified that the heart rate and its variability respond to the mental load sensitively (Umetani et al., 1998; Hjortskov et al., 2004; Wang et al., 2005). The changes in the heart rate during the education process greatly depend on the complexity of mental activity (Griniene, Vaitkevicius, 1998; Sharpley et al., 2000). Thus, in the last years there has been much evidence about the changes in the heart rate after the physical load depending on various factors (Victor et al., 1987; Zemaityte, 1997, Malik, Comm, 2000). It has also been found that after mental activities the arousal of the organism is expressed by the changes in the heart rate (Sharpley et al, 2000; Hjortskov et al, 2004; Wang et al., 2005).

However, we were unable to find data about the changes in the chronotropic activities of the heart and mental work capacity applying standardized physical load depending on the physical fitness of a person.

The changes in the heart rate during and after the physical load is a question of detailed discussion in literature, but only few studies about the heart rate changes during the mental activity and changes in the parameters of mental work after the physical load have been found. Although one may think that the functional activity of the heart after the physical load when the mental activity is performed should function in accordance with the body's physical qualities.

The aim of study was to establish the links between the changes in the heart rate variability and the mental work capacity after the standardized physical load in athletic and non-athletic females.

Objectives:

1. To analyze the recovery of the heart function and its variability after the standardized physical load and to compare the results between athletic and non-athletic females.
2. To examine the results of the females' mental work before and after the standardized physical load and to compare results between athletic and non-athletic females.
3. To investigate correlations between the changes in functional activity of the heart and mental work indices after the standardized physical load.

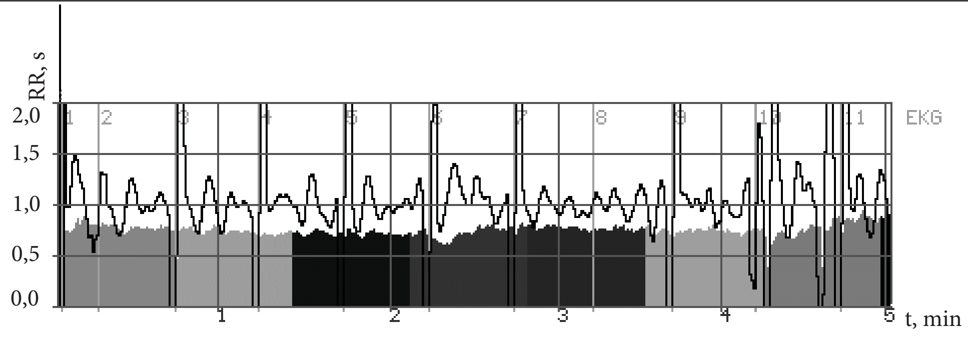
Hypothesis. Standardized physical load applied to athletic females can impact the recovery of the heart rate and its variability and contribute to their mental work.

RESEARCH ORGANIZATION AND METHODS

Subjects. Two groups of females participated in the study: ten athletic and eight non-athletic females. The mean age of the participants was 23.9 ± 6.44 (mean ± SD) years in the group of athletic women and 23.5 ± 2.39 years in the group of non-athletic females; their height was 173.1 ± 5.07 cm and 170.63 ± 6.16 cm respectively, and their weight — 65.4 ± 4.25 kg and 67.13 ± 12.86 kg. There were no differences in other body parameters.

Investigation protocol. The physical load was gradually increased to a fixed 150 W according to the Bruce's protocol (Bruce, Hornsten, 1969). The test was performed in the "Center for Research of Human Physical Abilities" at the Lithuanian Academy of Physical Education in 2003 with the

Fig. 1. **RR intervals during physical load and mental work test**



Note. 1. RR intervals in the state of rest.
2. RR intervals while females did mental work test.
3. RR intervals during physical load.
4. RR intervals after physical load.
5. RR intervals during mental work after physical load.

Note. * — significance was set before and after physical load, $p < 0.05$.

permission of the Lithuanian Biomedicine Research Ethics, No VIII–1679, registered on May 11, 2000. All the tests were performed between 8 and 10 a. m. The duration of each test was 30 min. During the whole test, 12-lead electrocardiogram (ECG) was recorded and RR intervals were measured using the specialized computer software "Kaunas—Load" (Vainoras, 2002). Before and after the standardized physical load the recipients performed the mental work test. The females worked for four minutes with special tables of letters, distributed in a casual way. During the first two minutes they crossed out the indicated letters and during the next two minutes they crossed out other indicated letters, if they managed to make up a certain unit (a fixed context) with other letters, then they had to underline it (Griniene, Vaitkevičius, 1998).

The whole test was divided into six phases, each lasting five for minutes: 1. In the state of rest ECG and RR intervals were recorded. 2. ECG and RR intervals were recorded while females were doing the mental work test. 3. ECG and RR intervals were recorded during the physical load according to the standardized Bruce's protocol (the same amount of load to all females). The initial load was 50 W, and it was increased every minute from 25 W to 150 W. 4. ECG and RR intervals were recorded during the recovery period after the physical load. 5. ECG and RR intervals were recorded during the mental work test after the physical load (see Fig. 1, example of RR intervals during the physical load and the mental test). 6. ECG and RR intervals were recorded during the rest phase.

Analysis of the heart rate and variability parameters. We analyzed and assessed the measures of heart rate and its variability indicators: the median of heart RR intervals in ms — Median RR, ms; standard heart RR intervals variability in ms — standard RR dispersion, ms; the percentage of standard heart rate variability — standard RR dispersion, %; heart rate variability RR after comparing the duration of heart cycles in ms — RR (j + 1) dispersion, ms; heart rate variability RRj after comparing the duration of heart cycles in percent — RR (j + 1) dispersion, %.

Analysis of the parameters of the mental work test. We considered the following mental work parameters: work intensity (the number of reviewed signs in four minutes), accuracy of work (the number of mistakes in 500 reviewed signs) and the efficiency coefficient Q which was estimated using the formula $Q = (i / 10)^2 / (i / 10) + a$, where i — the number of reviewed signs in four minutes, a — the number of mistakes.

Statistical analysis. The data were analyzed using the method of mathematical statistics, Excel 2000 software package. Means of parameters and the standard error of the means were calculated. One-way ANOVA tools were used (the data were unbalanced). The aim of the study was to compare the means of the studied parameters as one factor with and without sport activities. Significance was set at a level of $p < 0.05$. For the estimation of the relation between the parameters the correlation coefficient was calculated.

RESULTS

Alteration of heart rate indicators. Despite the general changes in the interval regulation, the analysis of the heart rate indicators showed that the heart rate and its variability varied in their size in the groups of athletic and non-athletic females after the standardized physical load. As we can see in Table 1, the heart rate — Median RR in ms did not differ in both groups performing mental work test before physical load ($p > 0.05$). However, the heart rate response to the standardized physical load varied. Median RR in ms of athletic females after the physical load during the mental work test returned to the previous state — it was practically the same as before the standardized physical load (the difference was 41.6 ms), while it was shorter among non-athletic females (the difference was 103 ms, $p < 0.05$). The duration of Median RR in ms after the physical load of athletic females was significantly longer (the difference was 59.4 ms ($p < 0.05$)) than of non-athletic females.

Analyzing standard RR dispersion in ms and percentage evaluation before physical load it was noticed that the variability of the heart rate in the both groups did not differ. As it is shown in Table 1, standard RR dispersion in ms and % among athletic females when the mental work test was performed after the physical load was similar to the one before the load (the differences were 27.2 ms and 3.4%, $p > 0.05$) while it was lower among non-athletic females (the differences were 41.3 ms and 3.8%, $p < 0.05$). Thus, after the physical load during the mental work test the variability of the heart rate among athletic females practically returned to its previous state compared to non-athletic females.

Comparing the duration of heart cycles — RR (j + 1) dispersion in ms and its percentage in both groups before physical load we can see that the heart rate variability was similar (Table 1). After the physical load RR (j + 1) dispersion in ms and its percentage recovered their normal state differently. Comparing RR (j + 1) dispersion in ms after load the heart rate variability of athletic females was similar to the one after the load (the difference was 22.1 ms, $p < 0.05$), though RR (j + 1) dispersion in percentage evaluation lagged behind (the difference was 2.4%, $p > 0.05$). RR (j + 1) dispersion in ms and its percentage evaluation among non-athletic females were not recovered after the physical load, and they were significantly lower (the differences were 40.7 ms and 3.3%, $p < 0.05$). After the physical load RR (j + 1) dispersion in ms in athletic females was more considerably noticeable than in non athletic females ($p < 0.05$). Thus, the heart rate variability comparing the duration of the heart cycles after the physical load was more noticeable and more similar to the previous one in athletic females compared to non athletic females before the physical load.

Mental work parameters. As we can see in Table 2, the indicators of mental work before and after the physical load show that in both groups they did not differ before the load ($p > 0.05$), because the women worked under similar conditions considering the intensity and the accuracy of the work. After the physical load athletic females worked more intensively — they reviewed more signs, but their accuracy was better — they rarely made mistakes, and their efficiency coefficient of mental work was higher than before the physical load. All the indicators of their mental work test increased ($p < 0.05$). Athletic females worked more intensively and accurately after the physical load than non-athletic females ($p < 0.05$). Physical load did not impact the mental work of non-athletic females: their work intensity slightly increased, but they made mistakes more often and their efficiency coefficient for mental work did not change ($p > 0.05$).

Correlation between the parameters of mental work and the functional parameters of the heart.

Table 1. **Heart rate and variability before and after standardized physical load while athletic and non-athletic female performed a mental work test**

Research participants / Indices of the heart	Athletic females		Non-athletic females	
	Before physical load	**After physical load**	**Before physical load**	**After physical load**
Median RR, ms	690 ± 27.4	648.4 ± 28.1	692 ± 25.6	589 ± 22.8*
Standard RR dispersion, ms	130.8 ± 11.4	103.6 ± 8.7	126 ± 10.8	84.7 ± 6.7*
Standard RR dispersion, %	19.2 ± 1.9	15.8 ± 0.9	18.1 ± 1.1	14.3 ± 0.6*
RR (j + 1) dispersion, ms	146.8 ± 12.3	124.7 ± 10.2	143.3 ± 9.1	102.6 ± 8.5*
RR (j + 1) dispersion, %	21.5 ± 2.0	19.1 ± 1.0	20.6 ± 0.8	17.3 ± 0.8*

Table 2. **Parameters of mental activity before and after physical load**

Indices of mental work \ Research participants	Athletic females		Non athletic-females	
	Before physical load	After physical load	Before physical load	After physical load
Intensity (i-number of reviewed signs)	653 ± 31.2	751 ± 32.9*	693 ± 44.7	718 ± 23.0
Accuracy (a-number of mistakes of 500 reviewed signs)	10.1 ± 1.4	5.5 ± 1.2*	6.3 ± 1.7	7.0 ± 2.0
Efficiency (Q– $(i/10)^2/(i/10)+a$	54.3 ± 2.4	67.9 ± 3.3*	60.3 ± 3.1	63.3 ± 1.9

Note. * — significance was set before and after physical load, $p < 0.05$.

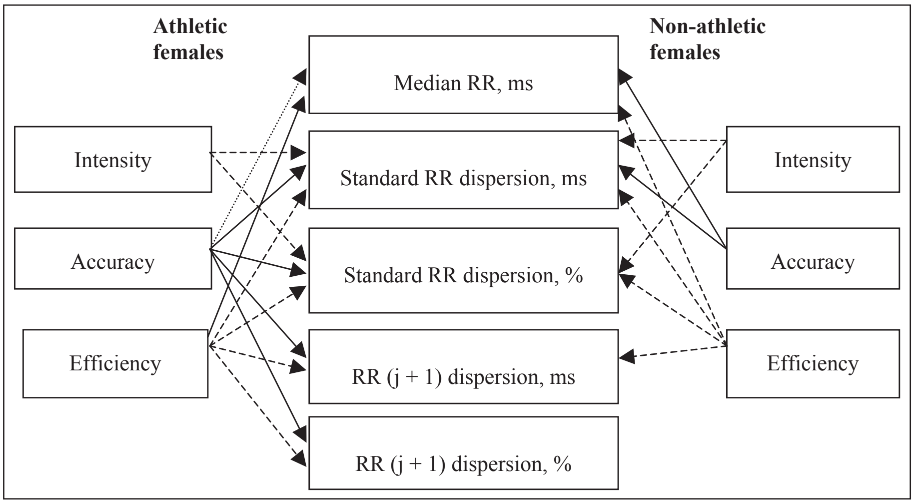


Fig. 2. **Relation between heart functional activity and mental work parameters of athletic and non-athletic females after physical load (dashed lines show negative correlation coefficient, solid lines reflect positive correlation)**

The links between the heart rate and the mental work were evaluated analyzing the data differences before and after physical load as well as their correlation. According to Figure 2, faster recovery of the heart rate after the physical load in athletic females correlated with the increase of accuracy and efficiency in their mental work. The heart rate variability indicators were practically linked to the indicators of their mental work. Better recovery of standard RR dispersion in ms and its percentage evaluation were related to the intensity of mental work (the females viewed more symbols), increase in work accuracy (they made fewer mistakes) and efficiency (the indicator increased). Better recovery of RR (j + 1) dispersion in ms and its percentage correlated with the increase in mental work accuracy and efficiency.

Slower heart rate recovery in non-athletic females after the physical load led to the reduction of mental work accuracy and resulted in the same level of efficiency. Slower recovery in standard RR dispersion in ms after the physical load led to slight changes in the intensity and the efficiency of the mental work and a small decrease in accuracy. The decrease in standard RR dispersion in ms and its percentage evaluation resulted in a slight change in the intensity and the efficiency of mental work. The correlations showed that the link between the percentage evaluations of RR (j + 1) dispersion in ms and mental work indicators were not distinguished.

THE DISCUSSION OF RESULTS

The analysis of the heart rate and its variability illustrated that the heart rate in the groups of athletic and non-athletic females before the physical load did not differ during the mental work test. The heart rate and its variability in athletic females after the physical load were the same as before the physical load ($p > 0.05$) whereas the indicators of non-athletic females were significantly lower ($p < 0.05$). This shows that the heart rate and its variability in athletic females recovered faster than in non-athletic females. This fact confirms the findings of other studies claiming that the heart rate recovery after the physical load is associated with continuous training (Zemaityte, 1997; Davy et al., 1998; Vainoras, 2002).

Both groups of females demonstrated similar intensity, accuracy and efficiency in their mental work test before the physical load. After the physical load the indicators of the mental work of athletic females increased while the results in the other group remained the same ($p > 0.05$). Thus, the results of athletic females after the physical load were better than of non-athletic females. We did not find any research data of this particular situation and the differences in the results of mental work. However, it has been found out that the heart rate alters under the circumstances of nervousness and tension (MacCraty et al., 2000; Hjortskov et al., 2004).

The stable correlation between the heart rate and the changes in the mental work test showed that the increase in the recovery of the heart rate and its variability was associated with improvement of the mental work. The slower recovery of the heart rate and its variability in non-athletic females was associated with a slight rise in level of their mental work. Faster recovery of the heart rate and its variability after the physical load revealed better functional abilities of the organism with resulted in the abilities to perform in the mental work test better. In the other group of females a slow recovery of the heart rate after the physical load and the processes of the regulative system might have directed the organism to another activity — mental work.

The research data confirmed our hypothesis. The standardized physical load in athletic and non athletic females had a different impact on the recovery of their heart rate and its variability, as well as their mental work. The faster recovery of the heart rate of athletic females affected the improvement of their mental work capacity.

CONCLUSIONS

1. After the physical load the intensity, accuracy and efficiency of mental work in athletic females increased whereas the intensity and efficiency in the other group remained practically unaltered and the accuracy decreased.
2. Faster recovery of the heart rate and its variability after the standardized physical load revealed better organism abilities of athletic females to perform in the mental work test; slower recovery of heart rate and its variability after the physical load revealed the lack of mental work indicators in non-athletic females.
3. Standardized physical load in athletic females impacted faster recovery of the heart rate and its variability and improved their mental work.

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RYŠYS TARP ŠIRDIES VEIKLOS DAŽNIO, VARIABILUMO IR PROTINIO DARBO KAITOS PO FIZINIO KRŪVIO

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SANTRAUKA

Pastaraisiais metais keičiasi požiūris į širdies veiklą. Laikoma, kad širdis ne tik užtikrina kraujotaką, bet taip pat siunčia nervinę, humoralinę, elektromagnetinę informaciją, sujungia kūno judesių, proto, emocijų ir dvasios bendravimą (Lacey J., Lacey B., 1978; Armour, Ardel, 1994; Goleman, 1995; Childre, Martin, 1999). Nustatyta, kad širdies ritmo greitis ir variabilumas jautriai reaguoja į protinį krūvį (Hjortskov et al., 2004; Wang et al., 2005). Tyrimų apie širdies pokyčius atliekant protinį darbą ir ryšį su fiziniu krūviu neaptikome.

Tyrimo tikslas — ištirti sportuojančių ir nesportuojančių merginų širdies ritmo dažnio ir variabilumo bei protinio darbingumo pokyčius po standartizuoto fizinio krūvio.

Tiriamąjį kontingentą sudarė dvi grupės: 10 sportuojančių ir 8 nesportuojančios merginos, kurių amžiaus vidurkis 23 metai. Tyrimas buvo atliekamas 2003 metais Lietuvos kūno kultūros akademijos Fizinių galimybių centre. Tyrimo trukmė 30 minučių. Visą tyrimo laiką registruota nenutrūkstamo ryšio elektrokardiogramaritmograma, duomenis fiksuojant pagal matematinio modelio programą kompiuteryje (Vainoras, 2002). Analizuoti šie širdies ritmo ir variabilumo parametrai: širdies ritmo medianas ms; standartinis ritmo variabilumas — dispersija RR ms; standartinis širdies ritmo variabilumas procentais — RR dispersija %; širdies ritmo variabilumas, lyginant vieno RRj ir kito širdies ciklo trukmę ms — RR (j + 1) dispersija ms; širdies ritmo variabilumas, lyginant vieno (RRj) ir kito širdies ciklo trukme procentais — RR (j + 1) dispersija %. Prieš standartizuotą fizinį krūvį (150 W) ir po jo tiriamosios atlikdavo protinio darbingumo testą (Grinienė, Vaitkevičius, 1998). Analizuotas protinio darbo intensyvumas (peržiūrėtas ženklų skaičius per 4 min), darbo tikslumas (bendras padarytų klaidų skaičius — 500 ženklų) ir produktyvumo koeficientas Q pagal formulę $Q = (a / 10)^2 / (a / 10) + b$, čia a — peržiūrėtų ženklų skaičius, b — padarytų klaidų skaičius.

Širdies ritmo rodiklių analizė parodė, kad po standartizuoto fizinio krūvio sportuojančių ir nesportuojančių merginų širdies susitraukimų dažnis ir variabilumas, nors ir pakluso bendram kaitos darbingumui, bet savo dydžiais skyrėsi. Širdies ritmo rodikliai prieš fizinį krūvį abiejų grupių merginų buvo panašūs. Prieš fizinį krūvį atlikus testą abiejų grupių merginų protinio darbingumo rodiklių pokyčiai nesiskyrė, jos dirbo panašiu intensyvumu, tikslumu ir produktyvumu. Po standartizuoto fizinio krūvio sportuojančių merginų širdies ritmo dažnio ir variabilumo rodikliai grįžo į pradinį lygį greičiau nei nesportuojančiųjų. Sportuojančių merginų protinio darbo intensyvumas, tikslumas ir produktyvumas po standartizuoto fizinio krūvio atliekant testą patikimai pagerėjo, o nesportuojančiųjų — nepakito. Po standartizuoto fizinio krūvio sportuojančių merginų širdies ritmo ir variabilumo rodiklių grįžimas į pradinį lygį buvo susijęs su protinio darbo rodiklių pagerėjimu. Nesportuojančių merginų širdies darbo ir variabilumo lėtesnis rodiklių grįžimas į pradinį lygį po standartizuoto fizinio krūvio jų protinio darbingumo neskatino.

Raktažodžiai: širdies susitraukimų dažnis ir variabilumas, fizinis krūvis, protinio darbo testas.

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