Journal of Physical Education and Sport ® (JPES), Vol. 25 (issue 2), Art 46 pp. 413 - 422, February 2025
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Acute and chronic effects of Pilates on the cardiovascular autonomic system

NAIARA RIBEIRO ALMEIDA[1], WASHINGTON PIRES[2], ESTEBAN AEDO MUÑOZ[3], ANDRÉIA CRISTIANE CARRENHO QUEIROZ[4], DIEGO IGNÁCIO VALENZUELA PÉREZ[5], OTÁVIO DE TOLEDO NÓBREGA[6], BIANCA MIARKA[7], CIRO JOSÉ BRITO[8]
[1,4,,8] Federal University of Juiz de Fora, Governador Valadares BRAZIL.
[2] Federal University of Ouro Preto, Ouro Preto BRAZIL.
[3] Chilean High-Performance Center, Santiago, CHILE
[3,4]. Universidad Metropolitana de Ciencias de la Educacion, Santiago, CHILE.
[5] Universidad Santo Tomás, Santiago, CHILE
[6] University of Brasilia, Distrito Federal, BRAZIL
[7] Federal University of Rio de Janeiro, Rio de Janeiro, BRAZIL.

Accepted for publication: February 15, 2025
DOI:10.7752/jpes.2025.02046

Abstract
Problem Statement: Few studies have been published regarding the effect of Pilates on the cardiovascular system. **Purpose:** to investigate the acute and chronic effects of Pilates on heart rate variability (HRV). **Methods:** a total of 25 inactive adult women were randomized into two groups: Pilates (n=14; 35.3±1.4 years) and Control (n=11; 36.0±1.3 years) groups. The training sessions were divided into warm-up, 11 Pilates exercises and stretching (~45 min; 3 times/wk.; 8 wk.). The control group relaxed (35 min; 3 times/wk.; 8 wk.). **Results:** there was a decrease in the time domain in the standard deviation– SD (80.1±24.4 vs. 50.3±14.8 ms; $p \leq 0.001$), variance (6939.1±3552.8 vs. 2736.8±1485.6 ms²; $p \leq 0.001$) and root mean square of standard deviation – RMSSD (49.1±22.6 vs.10.5±5.8 ms; $p \leq 0.001$) during the acute Pilates session when compared to the control group. The acute Pilates session induced a decrease in the low-frequency – LF (1,147.4±665.6 vs. 191.3±197.3 ms²; $p \leq 0.001$) and high-frequency – HF (932.5±888.4 vs. 72.1±82.4 ms²; $p \leq 0.001$), and an increase in the LF/HF ratio (5.7±2.4 vs. 1.9±1.2; $p \leq 0.001$) in the frequency domain. After 8 weeks of training, the acute Pilates session induced an increase in the LF/HF ratio (4.7±1.8 vs. 2.5±1.3; $p \leq 0.001$) and the RMSSD (14.85±5.6 vs. 29.27±19.7ms; $p \leq 0.001$). **Conclusion:** our data show that Pilates training induces acute responses exacerbated in the cardiac autonomic control pathways and that the 8 weeks of intervention promoted positive adaptations in simpatovagal balance. Therefore, we conclude that Pilates induces significant adaptations in the autonomic balance and can be used as a training method for improving cardiovascular performance.
Keywords: Exercise; strength training; flexibility training; heart rate variability; spectral analysis.

Introduction

Pilates is a resistance training method performed on specific devices which consists of springs with different tensions and accessories such as magic circle, elastic band, ball, and slide which allow increased resistance in the exercises (Bhadauria & Gurudut, 2017). Thus, Pilates is expected to be able to increase the strength of practitioners (Cruz-Díaz et al., 2018). This method is widely indicated because it has a beneficial effect on health status, relieves chronic low back pain and improves quality of life (Bhadauria & Gurudut, 2017; Cruz-Díaz et al., 2018). In addition, it is indicated for increasing flexibility, muscular endurance, balance, and functional capacity (Bird et al., 2012; Curi et al., 2018; de Oliveira et al., 2015; Markovic et al., 2015; Rayes et al., 2019), also being recommended for individuals who have heart failure aiming to improve the cardiovascular health (Fernández-Rodríguez et al., 2019; Guimarães et al., 2012).

Regarding the effect of Pilates on cardiovascular health, studies have been carried out on this subject. A meta-analysis indicated that Pilates has a positive effect on the cardiovascular system, both in healthy subjects (Fernández-Rodríguez et al., 2019) and in those with cardiovascular disease (Çetin et al., 2019; Fernández-Rodríguez et al., 2019). Tinoco-Fernández et al. (2016) found that 10 weeks of Pilates were sufficient to improve cardiovascular parameters (decrease in heart rate and gas exchange ratio, and an increase in peak VO_2, VO_2max and maximum ventilation). Practicing Pilates offers benefits for the cardiovascular system, particularly through its focus on respiratory control during movement (Fernández-Rodríguez et al., 2019; Tomasi et al., 2024). This method enhances the strength of inspiratory and expiratory muscles (Bağlan Yentür et al., 2024), leading to improved respiratory efficiency and increased oxygen flow to muscles during physical activity (Tarnas et al., 2024). Enhanced oxygen transport promotes better peripheral blood circulation (Tinoco-Fernández et al., 2016). In fact, a recent meta-analysis has shown that Pilates is safe for hypertensive patients and can be effectively integrated into rehabilitation programs (González-Devesa et al., 2024). Another significant benefit of Pilates

Corresponding Author: CIRO JOSÉ BRITO, E-mail: cirojbrito@gmail.com

training on the cardiovascular system is its impact on resting heart rate control (Gultekin et al., 2024; Tarnas et al., 2024). Gultekin et al. (2024) note that a typical Pilates session involves cardiopulmonary exercises comparable to those found in moderate-intensity aerobic workouts. Furthermore, a recent narrative review highlighted that long-term Pilates training positively influences cardiovascular health in patients with heart conditions (Tarnas et al., 2024).

Despite de effect in the cardiovascular health, to the best of our knowledge, there is limited evidence regarding the influence of Pilates on heart rate variability (HRV). HRV describes the oscillations of the intervals between heartbeats, and is widely used to analyze modulation of the autonomic nervous system (Meeusen et al., 2006). HRV reflects the balance between the sympathetic and parasympathetic nervous systems. During rest, HRV is controlled by the parasympathetic system, which modulates the action of the cardiac vagal nerve. In general, the action of the parasympathetic on the heart of a healthy subjects results in a higher variation in the heartbeat rhythm (High HRV). On the other hand, a Low HRV values indicate insufficient adaptation of autonomic nervous system in response to environmental stimuli (Drury et al., 2019; McCraty & Shaffer, 2015; Tomasi et al., 2024). In fact, studies have shown the clinical relevance of HRV in the manifestation of some diseases such as obesity (Strüven et al., 2021), depression, gastrointestinal disorders (Drury et al., 2019) and lower back pain (Sanchis-Soler et al., 2024). It is known that age and fitness level modulate HRV, thus, it is expected that subjects undergoing Pilates training obtain similar effects (Berntson et al., 1997; Drury et al., 2019). Before conducting this study, we performed a literature search and discovered only a few studies exploring the effect of Pilates on HRV. In an acute design, Pilates can promote a positive effect on HRV because it presented a reduction in rMMSSD and pNN50 after an exercise session (Rocha et al., 2020) or not to produce any acute effects on HRV (Batista et al., 2019). In addition to the still contradictory results, the cited studies only measured the acute effects of exercise, and in samples which presented health conditions that can affect autonomic responses, such as hypertension (Rocha et al., 2020) and old age (Batista et al., 2019). In a recent study, Yoo (2022) found that practicing Mat Pilates (performed on the ground without equipment) enhances the responsiveness of the autonomic nervous system. Since HRV is regulated by this system, we believe that chronic Pilates practice can lead to positive adaptations in both the time and frequency domains, which are indicators of improved cardiovascular health (Joyce & Barrett, 2019). We found studies highlighting the chronic benefits of Pilates on women's mental health (Ju et al., 2023) and its role in breast cancer treatment (Espíndula et al., 2017). To the best of our knowledge only, a study evaluated the chronic effect of Pilates in HRV in women. Adıgüzel et al. (2023) performed 20 sessions in 10-wks. The main results indicated a positive chronic effect on frequency domains parameters (LF and HF). In contrast to the previous study, our protocol was characterized a progressive training regimen that increased intensity by reducing the interval every two weeks, aiming to enhance outcomes in the time domain. Therefore, the present study aimed to investigate the acute and chronic effects of Pilates on HRV in healthy young adult women. We hypothesized that the Pilates group would exhibit both acute and chronic adaptations in the time-domain and frequency-domain parameters HRV.

Methods

Experimental approach

The present study is an experimental protocol of a chronic investigation in which a sample of inactive adult women was randomized into two groups: Pilates (Case) and Relaxation (Control). All participants were measured before and after 24 sessions. A dissemination campaign was initially carried out with possible participants. Next, we held an information meeting to explain the adopted objectives and procedures, as well as the associated risks. Those who met the inclusion criteria and consented to participate answered the physical activity readiness questionnaire (PAR-q). After this stage, anthropometric measurements, muscle strength test and familiarization with Pilates training (test group only) were performed. After 3 days of familiarization, an acute session was performed to record HRV data, and the intervention began. The HRV data was also recorded again in the last session. The strength measurements were carried out one day later. Figure 1 shows the organization of experimental procedures.

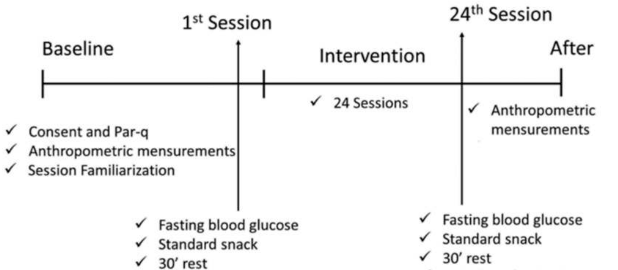

Figure 1. Chart of experimental procedures.

Ethics and participant selection

This protocol was approved by the Research Ethics Committee of the university (Protocol 1.089.162) prior to data collection, respecting the standards established by the Helsinki declaration for experiments on human beings. Each participant signed an informed consent form before starting data collection agreeing with the processes and procedures. Women considered fit to practice physical exercise (PARq) participated in the study. All were instructed to maintain their dietary routine during the intervention period. The inclusion criteria were: i) not having participated in another training program in the last two months, and ii) being between 20-40 years old. The exclusion criteria were: i) having a history of injuries in the previous six weeks, ii) being hypertensive or diabetic or presenting any other condition which would put their health at risk; iii) not participating in all stages of the project; and iv) wanting to stop participation.

The minimum sample size was determined based on a prior study assessing the chronic effects of Pilates on HRV (Adıgüzel et al., 2023). To achieve a target effect size of 0.30, with an alpha of 0.05 and a power of 0.95, the software estimated that at least 11 participants would be required per group (Granmo 7.12, IMIM, Barcelona, Spain). Initially, 52 volunteers agreed to participate in the study. However, 17 did not meet the inclusion criteria. Therefore, 35 were randomly allocated to the Pilates (n=17) and Control (n=18) conditions. After start the intervention; 13 dropped out because they did not adapt to the research procedures or due to a lack of time. Thus, the final sample of this study was composed of 25 participants (Pilates n = 11; age: 35.3 ± 1.4 years; Weight: 59.5 ± 1.9 kg; Height: 1.6 ± 0.01; %FAT: 25.4 ± 1.1; Control n = 14; age: 36.0 ± 1.3 years; Weight: 60.5 ± 1.6kg; Height: 1.6 ± 0.01; %FAT: 25.5 ± 1.2). Figure 2 shows the sample selection chart of procedures.

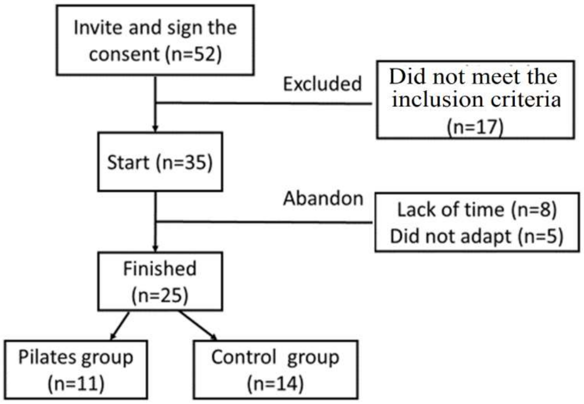

Figure 2. Chart of participants selection.

Anthropometry

Body mass was measured using a 100-g precision scale (Glass-Pro, G-Tech©, China). Height was measured with a 1-cm precision stadiometer (Model 405, Cescorf©, Brazil). Body mass and height were used to calculate the body mass index (BMI) = body mass (kg)/height (m^2). The body density was calculated using the equation for women between 18-51 years of age by Filardo and Petroski (2007). The fat percentage was estimated from the body density using the Siri equation (Siri, 1956). Fat-free mass and fat mass were estimated through the difference between body mass and fat percentage.

Heart Rate Variability (HRV)

Heart rate was continuously monitored by telemetry during data collection using a cardiofrequencymeter (Polar RS800CX, Kempele, Switzerland). The measured variables were processed in a specific software program to record HRV values (Polar Pro Trainer 5; PPT 5, Kempele, Switzerland) and later analyzed in the CardioSeries 2.4 software. The generated records were analyzed for the presence of spurious values. When detected, they were corrected and stored on a hard disk as a data file in text format.

For data analysis, 10 minutes of rest period were selected during the training session and during recovery. The measurement range analyzed from rest and recovery was selected from 10 minutes to 20 minutes. During the intervention (Pilates or Control) we used the 10-minute records referring to the middle of the session. Spectral density was obtained by rapid Fourier transformation and segment size was fixed at 512 points with 50% overlap. Spectral components were evaluated using band widths that were previously described for VLF bands from 0.00 to 0.4 Hz; LF from 0.04 to 0.15Hz; and HF from 0.15 to 0.4 Hz (Camm et al., 1996).

Training protocol (Pilates group)

This protocol was developed based on previously published papers (Cruz-Díaz et al., 2018; Curi et al., 2018; Hoseini Niya et al., 2020; Roh, 2016). The Pilates training protocol consisted of 24 sessions (3 times/wk.). Each session consisted of warm-up (5 min.), main exercises and relaxation (5 min.). The first two weeks lasted 48 minutes and 30 seconds, the third and fourth 46 minutes and 40 seconds, the fifth and sixth 44 minutes and 50 seconds, the last two weeks lasted 43 minutes. During the warm-up the participant remained lying down, and the Pilates breathing technique was performed in the first minute only; the pelvis movement was added in the second minute; then the arms were positioned in front of the body and the shoulder was rotated in the third minute; lateral rotation of the neck in the fourth minute; and the lateral and medial rotation of the hips was performed in the last minute. The main part consisted of 11 exercises performed twice as a circuit, adding 22 stimuli of 60 seconds each.

The main part of the workout featured 11 exercises organized in a circuit format, totaling 22 sets of 60 seconds each. Each exercise comprised 10 repetitions, with each repetition lasting 6 seconds (3 seconds for both the concentric and eccentric phases). Participants also focused on controlled breathing: exhaling during the concentric phase and inhaling during the eccentric phase. For the upper body, one exercise targeted the pectoral muscles, deltoids, and triceps (Exercise 7), while two exercises focused on the rib cage and biceps (Exercises 1, and 2). The lower body segment included four exercises: two for knee and hip flexion and extension in abduction, and one specifically for knee flexion and extension (Exercises 3, 4, 9 and 10). Lastly, four exercises concentrated on the trunk muscles (Exercises 5, 6, 8 and 11). To increase intensity throughout the training weeks, the recovery between sets was done regressively, the recovery for the first two weeks was 45 seconds, the third and fourth 40 seconds, the fifth and sixth 35 seconds, and 30 seconds in the last two weeks. The main part of the workout lasted approximately 36 minutes during the first and second weeks, 34 minutes in the third and fourth weeks, 32 minutes in the fifth and sixth week, and 30 minutes in the final two weeks. The Swiss ball, elastic, step barrel, half ball, slide board, chair, wall unit, roller and solo pilates technique were used to perform the exercises. stretching of the adductors of the lower limbs, posterior chain, shoulder rotation, cervical stretching and trunk rotation were performed in relaxation. Figure 3 showed the eleven exercises performed along the workout protocol.

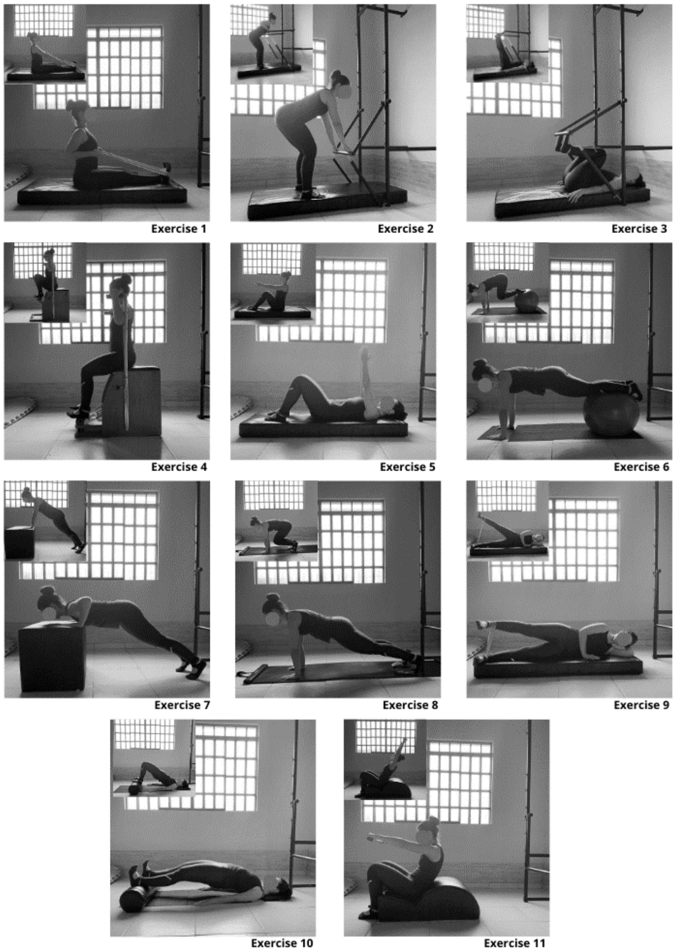

Figure 3. Main part of the workout performed by Pilates group. Upper-limbs exercises: 1 – Rowing with band; 2 – Rowing with wall unit and; 7 – Push up. Lower-limbs exercises: 3 – Leg press; 4 – Double leg pump heels; 9 – Side hip abduction and; 10 – Shoulder bridge with knee flexion and extension. Trunk exercises: 5 – Roll up (knees in flexion); 6 – Knee stretches on the ball; 8 – Knee stretches on the slide and; 11 – Back extension.

Table 1 shows the protocol which corresponds to the 24 sessions performed by the Pilates group.

Table 1. Training protocol carried out by the Pilates group (24 sessions).

Component	Weeks 1-2	Weeks 3-4	Weeks 5-6	Weeks 7-8
Intensity	---	---	---	---
Volume	2 sets x 10 rep.	2 sets x 10 rep.	2 sets x 10 rep.	2 sets x 10 rep.
Duration of rep.	6 seconds	6 seconds	6 seconds	6 seconds
Pause	45 seconds	40 seconds	35 seconds	30 s seconds
Density	1.33	1.5	1.71	2.0
No. of exercises	11	11	11	11

Rep. = repetition.

Relaxation protocol (control group)

The control group performed 24 relaxation sessions lasting 35 minutes, three times a week. The duration of the control session was aligned to match that of the main Pilates group training session. All sessions were guided by sounds of nature through the Soothing Sleep Sounds app- Copyright© 2018 Phase4 Mobile, Inc. Version 2.0.

Statistical analysis

Firstly, we tabulate the data in a spreadsheet, followed by conducting the Kolmogorov-Smirnov test to assess the normality of all variables. For the inferential analysis, we employed generalized estimating equations for longitudinal data, incorporating covariate group interactions and measurement moments as recommended by Liu and Colditz (2017). Bonferroni's post-hoc was used when significant differences were detected. A value of p≤0.05 was used and all calculations were performed using the SPSS 20.0 software for all analyzes.

Results

Time domain

Figure 4 presents the results in the time domain for the Pilates and Control groups measured in the acute and chronic session.

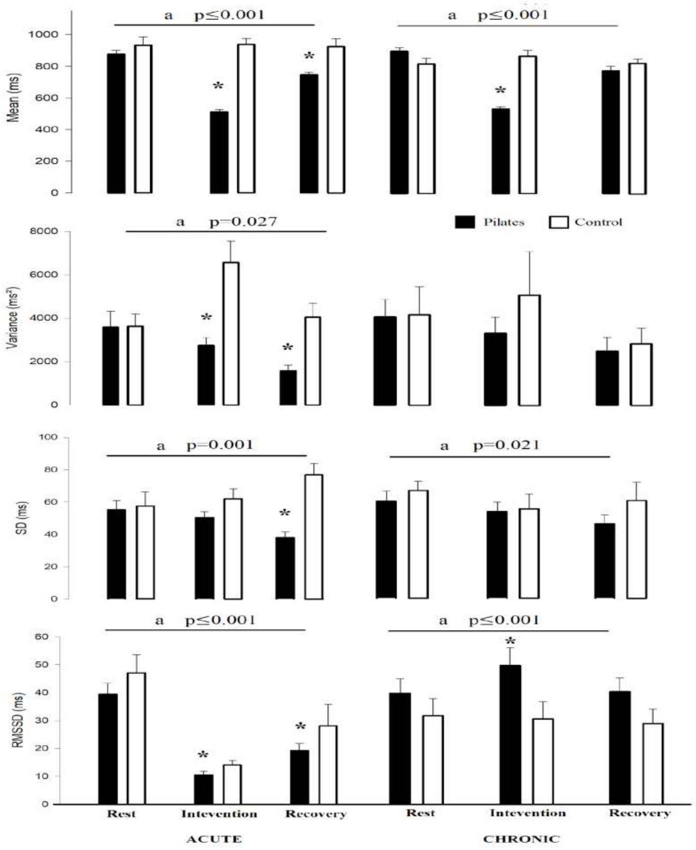

Figure 4. Heart rate variability parameters in time domain during an acute Pilates session (ACUTE) and after 8 weeks of training (~45 min; 3 times/wk.; CHRONIC). Mean = mean heart interval; Variance = (mean heart interval) ²; SD = standard deviation; RMSSD = mean square root of the difference of successive wave range); * = different from the Control group.

Statistical differences were observed for this set of variables in many comparisons. We chose to only report those which are relevant to elucidating the objectives of this study to better visualize the results. There was an effect of group interaction and measurement moment for the mean variable (W = 316.819; df = 5.0; $p \leq 0.001$), in which the means observed in the Pilates group at acute rest were statistically higher in relation to those observed in acute recovery [$p \leq 0.001$; 132.5 (85.6; 179.4 ms)] similar results were observed between the chronic rest and recovery means [$p \leq 0.001$; 126.1 (59.3; 193.0 ms)]. Pilates showed lower averages for the comparisons between groups in the acute intervention [$p \leq 0.001$; -429.5 (-507.7; -351.3 ms)], acute recovery [p=0.001; -176.8 (-277.7; -75.8 ms)] and chronic intervention moments [$p \leq 0.001$; -347.9 (-430.5; -265.4, ms)].

For SD means, there was an effect of group interaction and measurement moment (W = 52.075; df = 5.0; $p \leq 0.001$). Similar to that observed for the mean variable, there was a significant difference between acute rest and recovery [p=0.001; 17.2 (4.8; 29.7 ms)] and chronic [p=0.021; 13.9 (1.0; 26.8 ms) for the Pilates group. There was a group interaction and measurement moment effect for the variance (W = 19.501; df = 5.0; p = 0.02). Higher means were observed for the Pilates group at rest versus acute recovery [p = 0.027; 2,005.7 (122.3; 3,889.1 ms^2)]. The means observed in the Control for the comparisons between groups were higher in the intervention [$p \leq 0.001$; 3,843.6 (1,793.8; 5,893.4 ms^2)] and acute recovery [$p \leq 0.001$; 2,510.4 (1,108.3; 3,912.5 ms^2)]. There was also a group interaction and measurement moment effect for the RMSSD means (W = 87.885; df = 5.0; $p \leq 0.001$), when compared the moments, Pilates showed differences between the Rest, intervention and recovery at acute measurement [$p \leq 0.001$ for all comparison; 28.9 (17.1; 40.8) ms vs. intervention; 20.1 (10.1; 30.2) ms vs. recovery]. At the same moment Control showed differences between rest vs. intervention [p=0.02; -8.9 (-15.8; -2.0 ms)]. At the Chronic moment Pilates showed the same differences observed at acute [$p \leq 0.001$ for all comparison; 33.4 (16.3; 50.6) ms vs. intervention; 19.1 (7.4; 30.7) ms vs. recovery]. For group comparison there were differences at acute exercise [$p \leq 0.001$; -39.0 (-51.1; -26.9 ms)], acute recovery [$p \leq 0.001$; -20.2 (-30.4; -10.0 ms)] and chronic exercise [p=0.01; -19.2 (-33.7; -4.6. ms)] vs. Control.

Frequency domain

Figure 5 presents the results in the frequency domain for the Pilates and Control groups measured in the acute and chronic session.

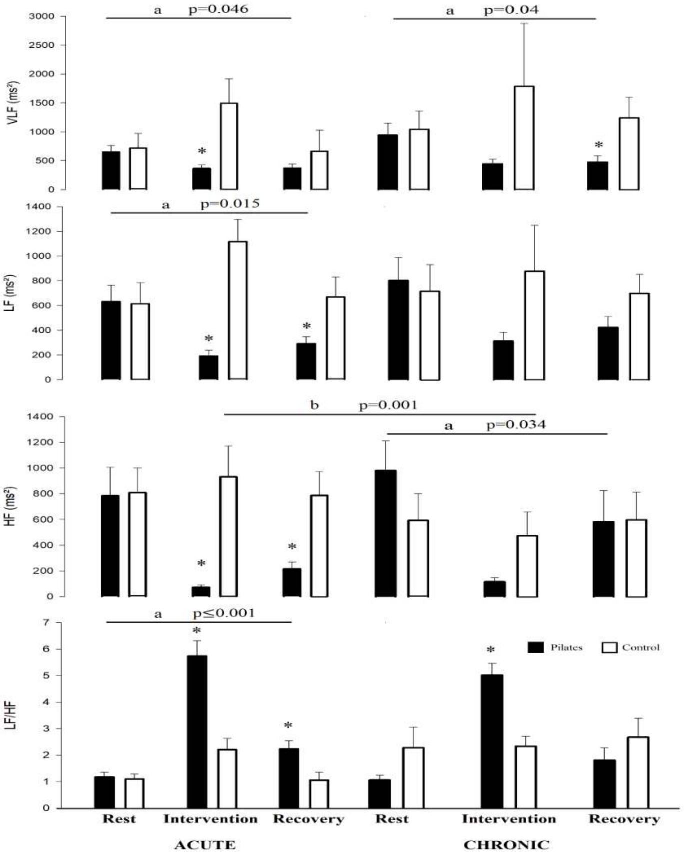

Figure 5. Heart rate variability parameters in frequency domain during an acute Pilates session (ACUTE) and after 8 weeks of training (~45 min; 3 times/wk.; CHRONIC). VLF = very low frequency; LF = low frequency; HF = high frequency; LF/HF = sympathovagal balance; * different from the Control group.

There was a group interaction and measurement moment effect for the VLF variable (W = 21.128; df = 5.0; p = 0.001), where the means observed in the Pilates group were higher at rest compared to recovery at the acute [p=0.046; 275.9 (2.1; 549.6 ms^2)] and chronic moments [p=0.04; 465.3 (10.2; 920.5 ms^2)], between the groups Control showed a significative lower variability at acute intervention [p=0.005; -1,168.3 (-1,979.1; -357.5 ms^2)] and chronic recovery [p=0.022; -816.3 (-1,512.3; -120.3 ms^2)]. In addition, there was a group interaction and measurement moment effect for the LF variable (W = 26.621; df = 5.0; p≤0.001), where the means observed in the Pilates group were increased frequency at rest in acute intervention [p=0.016; 440.4 (44.8; 836.0 ms^2)] and recovery [p=0.015; 339.8 (36.0; 643.6 ms^2)] vs. rest. There was also a difference between acute intervention [p≤0.001; -882.1 (-1,238.7; -525.5 ms^2)] and recovery [p=0.009; -426.5 (-744.3; -108.7 ms^2)].

There was a group interaction and measurement moment effect for the HF variable (W = 40.538; df = 5.0; p≤0.001), where the means observed in the Pilates group were higher at rest compared to intervention at acute moment [p=0.021; 712.2 (57.0; 1,367.5 ms^2)] at chronic moment we found differences between the rest vs. exercise [p=0.002; 865.4 (208.1; 1,522.7 ms^2)] and recovery [p=0.035; 398.9 (14.7; 783.2 ms^2)]. For the Control, the means observed a significative difference between the chronic rest vs chronic intervention [p=0.047; 196.9 (1.1; 392.7 ms^2)]. Between the groups, there was a significant difference at acute [p≤0.001; -838.3 (-1,309.9; -392.7 ms^2)] and chronic intervention [p=0.003; -550.7 (-913.1; -188.2 ms^2)] and acute recovery [p=0.046; -377.0 (-747.9; -6.2 ms^2)]. There was also a group interaction and measurement moment effect for the LF/HF (W = 70.734; df = 5.0; p≤0.001), where the means observed in the Pilates were lower at acute rest vs. intervention [p≤0.001; -4.6 (-6.3; -2.8)] and recovery [p≤0.001; -1.1 (-1.7; -0.4)] and chronic rest vs. chronic intervention [p≤0.001; -4.0 (-5.4; -2.5)]. Finally, there was a difference between the acute intervention [p≤0.001; 3.6 (2.3; 5.0)], recovery [p=0.006; 1.1 (0.3; 1.8)], and chronic intervention [p≤0.001; 2.7 (1.5; 3.9)] for the comparison between groups.

Discussion

Pilates training can be acutely (Rocha et al., 2020) and chronically (Adıgüzel et al., 2023) beneficial for HRV modulation. To the best of our knowledge, (Adıgüzel et al., 2023) were the only ones to measure the chronic effect of Pilates on HRV in women, however, we sought in our protocol to establish a progressive training load, where we reduced the interval between exercises by 5 seconds every two complete weeks of training. Our main results indicated that Pilates training acutely induced a significant decrease in HRV when compared to control in both the time domain and the frequency domain parameters. Our results corroborate the findings of two studies that measured the chronic effect of Pilates on HRV. Gouveia et al. (2022) observed that 8 weeks (2 workouts per week) of training have a positive effect on autonomic modulation in diabetics of both sexes. Meanwhile, Adıgüzel et al. (2023) observed after 10 weeks (2 workouts per week) positive modulation in the frequency domains. In addition to the agreement with the two chronic studies, our results also indicated positive modulation in the time domain. Despite the similar duration, our study totaled 24 training sessions, thus, we suggest that the higher weekly frequency associated with progressive intensity, adopted in our protocol, is necessary to observe positive modulation in both HRV domains. The effect of the volume of weekly Pilates training has not been the subject of scientific investigations, however a meta-analysis for the reduction of back pain suggested that there is a positive effect depending on the number of sessions performed per week (Fernández-Rodríguez et al., 2022). The data obtained in the present study are relevant because higher HRV, in the frequency and time domains, are associated with lower risk of all causes of death and cardiovascular events (Fang et al., 2020).

The SD and variance variables in the time domain, which indicate the general cardiac capacity to adjust to different stressors (Berntson et al., 1997), showed a lower variability during the Pilates session. These results show that Pilates induces increased cardiovascular demand and consequently reduced vagal modulation, as verified by the decrease in the RMSSD parameter during the session. This set of results shows the cardioprotective effect of chronic pilates practice. A study with US war veterans monitored for 12 years indicated that an increase in 1SD reduces the risk of death by 22%. Also, our results corroborates the findings of Rocha et al. (2020) who verified a decrease in this parameter after a session. Furthermore, Pilates induced a decrease in the LF component in the frequency domain, which indicates a mixture of sympathetic and parasympathetic modulation. There was also a decrease in the HF component, which indicates a reduction in vagal modulation. In turn, the LF/HF ratio was calculated to specifically analyze the impact of Pilates on sympathetic modulation, and this parameter increased during the session. Together, these results indicate that Pilates training acutely represents a significant stimulus on the autonomic system, which is a mediator of cardiovascular aerobic adaptations.

The rest measures for the chronic results showed no differences in the parameters in the time domain, as well as in the frequency domain when comparing Pilates with Control. These results showed that 24 Pilates sessions with the load configuration used in the present study in healthy young adult women did not induce chronic adaptations in the autonomic nervous system. The exercise volume and the amount of muscle mass mobilized in this protocol possibly did not generate enough adaptations to lead to a significant difference between the group which did Pilates and the control. In fact, the meta-analysis of Sandercock et al. (2005) emphasizes that the chronic effects of HRV training are inconsistent, thus justifying the development of new chronic protocols which investigate this topic. We believe that future studies can modify this protocol by increasing the frequency of repetitions and also the stimulation time or choose exercises which involve greater muscle volume.

Our results also showed that the acute Pilates session was able to change the parameters in the time domain (SD, variance and RMSSD). These parameters have been widely used in the area of health and sports sciences to verify the acute effects of various types of exercises on the autonomic nervous system (McCraty & Shaffer, 2015). Aerobic exercises are those which are known to increase cardiovascular capacity and acutely alter HRV parameters in the time domain (Sandercock et al., 2005). It should be noted that we had a greater emphasis on strength stimuli in our protocol. Previous studies have shown that acute high or low intensity (Rezk et al., 2006) or chronic (Forte et al., 2003; Kanegusuku et al., 2015) resistance training has little or no effect on HRV. According to Forte et al. (2003), the training intensity is possibly the main variable to determine the absence of effect of the resistance training in producing cardiac autonomic variations. This is because regardless of the intensity, the stimulus of each series lasted between 2 and 3 minutes per muscle group, and it is necessary to cause a higher stress level to observe due changes. Furthermore, the stimulus time in our study was shorter (Table 1). A training compliment with aerobic activities is possibly necessary to induce positive chronic adaptations in HRV (Masroor et al., 2018).

Therefore, it is questioned whether Pilates would represent a sufficient stimulus to induce modulation in the parameters measured in the present study. According to the acute data, it can be said that Pilates is an important stressor for the autonomic nervous system, so it is expected that this training model promotes improvement in cardiac function (Perini & Veicsteinas, 2003). The RMSSD is considered an important parameter for control and training prescription, given that it estimates vagal adaptations and Pilates was able to sharply reduce this parameter. Our results corroborate those observed by Adıgüzel et al. (2023) either through Pilates training or through the addition of respiratory control exercises (5s/5s inhalation and exhale cycle). A single acute session was able to induce autonomic adjustments with a decrease in LF and HF parameters in response to sympathetic and parasympathetic adaptations, as well as an increase in the LF/HF parameter which indicates sympathetic modulation caused by training (Berntson et al., 1997; Masroor et al., 2018). This study also observed that the acute Pilates session allowed for significant changes in autonomic modulation in the frequency domain. In addition, when analyzing the chronic effects of Pilates in the time domain, the cardiovascular adaptations that occurred in the acute post-intervention session were analogous to the acute responses in the pre-intervention session, however there was no improvement in cardiac capacity in the autonomic modulation parameters when compared to the relaxation group. The RMSSD can be used for training prescription (Masroor et al., 2018; Perini & Veicsteinas, 2003), since this index is increased in trained individuals compared to sedentary people (Benichou et al., 2018). Although we did not observe chronic differences regarding the RMSSD, it is possible to change the configuration of the training load, such as frequency of repetitions and stimulation time, making the training more aerobic, allowing for greater cardiovascular adaptations (Masroor et al., 2018).

We did not observe differences during the training moments or the post-intervention recovery of the LF and HF variables in the frequency domain, in which there was a reduction in vagal modulation; however, there was no significant difference. On the other hand, the LF/HF ratio increased, showing that the acute post-intervention session was able to increase sympathetic activity (Bond Jr et al., 2016), corroborating with studies that observed that exercise is capable of generating adaptations in modulating the sympathetic system (Berntson et al., 1997; Masroor et al., 2018; Molina et al., 2016). Our results must be interpreted in light of limitations, such as the small sample size. For future studies, we suggest new protocols could be carried out with a larger sample size and combined with complementary aerobic training. Taken together, the data presented herein show promising information on acute and chronic effects of the method. In this study, we sought to provide as much detail as possible regarding our training program. This action aims to help guide professionals who work with Pilates so that they can apply this protocol in practice.

Conclusion

Based on the methods established for the present study and the results obtained, we conclude that a progressive intensity protocol can result in greater HRV in both time and frequency domains, especially for the LF/HF ratio and the RMSSD. Thus, the present study indicates the chronic practice of Pilates as an important modulator of HRV, which can result in a greater cardioprotective effect.

References

Adıgüzel, S., Aras, D., Gülü, M., Aldhahi, M. I., Alqahtani, A. S., & Al-Mhanna, S. B. (2023). Comparative effectiveness of 10-week equipment-based pilates and diaphragmatic breathing exercise on heart rate variability and pulmonary function in young adult healthy women with normal BMI – a quasi-experimental study. *BMC Sports Science, Medicine and Rehabilitation*, *15*(1), 82.

Bağlan Yentür, S., Saraç, D. C., Sari, F., Tore, G., Bilici Salman, R., Akif Öztürk, M., & Oskay, D. (2024). The effects of Pilates training on respiratory muscle strength in patients with ankylosing spondylitis. *Physiotherapy Theory and Practice*, *40*(1), 31-41.

Batista, J. P., Mariano, I. M., Souza, T. C., Costa, J. G., Giolo, J. S., Cheik, N. C., Espindola, F. S., Everman, S., & Puga, G. M. (2019). The acute effects of mat Pilates on hemodynamic and salivary nitrite responses after exercise in postmenopausal women. *J Aging Phys Act*, *27*(3), 371-377.

Benichou, T., Pereira, B., Mermillod, M., Tauveron, I., Pfabigan, D., Maqdasy, S., & Dutheil, F. (2018). Heart rate variability in type 2 diabetes mellitus: A systematic review and meta–analysis. *PloS one*, *13*(4), e0195166.

Berntson, G. G., Thomas Bigger Jr, J., Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., Nagaraja, H. N., Porges, S. W., Saul, J. P., & Stone, P. H. (1997). Heart rate variability: origins, methods, and interpretive caveats. *Psychophysiol*, *34*(6), 623-648.

Bhadauria, E. A., & Gurudut, P. (2017). Comparative effectiveness of lumbar stabilization, dynamic strengthening, and Pilates on chronic low back pain: randomized clinical trial. *J Exerc Rehab*, *13*(4), 477.

Bird, M.-L., Hill, K. D., & Fell, J. W. (2012). A randomized controlled study investigating static and dynamic balance in older adults after training with Pilates. *Arch Phys Med Rehab*, *93*(1), 43-49.

Bond Jr, V., Curry, B. H., Kumar, K., Pemminati, S., Gorantla, V. R., Kadur, K., & Millis, R. M. (2016). Nonlinear Conte-Zbilut-Federici (CZF) Method of Computing LF/HF Ratio: A More Reliable Index of Changes in Heart Rate Variability. *J Pharmacopuncture*, *19*(3), 207.

Camm, A. J., Malik, M., Bigger, J. T., Breithardt, G., Cerutti, S., Cohen, R., Coumel, P., Fallen, E., Kennedy, H., & Kleiger, R. (1996). Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology.

Çetin, S., Ece, C., Şen, M., Çetin, H. N., & Aydoğan, A. (2019). The Effects of Pilates and Aerobic Exercise on Blood Pressure, Heart Rates, and Blood Serum Lipids in Sedentary Females. *Journal of Education and Training Studies*, *7*(4), 229-235.

Cruz-Díaz, D., Romeu, M., Velasco-González, C., Martínez-Amat, A., & Hita-Contreras, F. (2018). The effectiveness of 12 weeks of Pilates intervention on disability, pain and kinesiophobia in patients with chronic low back pain: a randomized controlled trial. *Clin Rehab*, *32*(9), 1249-1257.

Curi, V. S., Haas, A. N., Alves-Vilaça, J., & Fernandes, H. M. (2018). Effects of 16-weeks of Pilates on functional autonomy and life satisfaction among elderly women. *J Bodywork Mov Ther*, *22*(2), 424-429.

de Oliveira, L. C., de Oliveira, R. G., & de Almeida Pires-Oliveira, D. A. (2015). Effects of Pilates on muscle strength, postural balance and quality of life of older adults: a randomized, controlled, clinical trial. *J Phys Ther Sci*, *27*(3), 871-876.

Drury, R. L., Porges, S., Thayer, J., & Ginsberg, J. (2019). Heart rate variability, health and well-being: A systems perspective. *Frontiers Pub health*, *7*, 323.

Espíndula, R. C., Nadas, G. B., Rosa, M. I. d., Foster, C., Araújo, F. C. d., & Grande, A. J. (2017). Pilates for breast cancer: A systematic review and meta-analysis. *Revista da Associação Médica Brasileira*, *63*(11), 1006-1012.

Fang, S.-C., Wu, Y.-L., & Tsai, P.-S. (2020). Heart Rate Variability and Risk of All-Cause Death and Cardiovascular Events in Patients With Cardiovascular Disease: A Meta-Analysis of Cohort Studies. *Biological Research For Nursing*, *22*(1), 45-56.

Fernández-Rodríguez, R., Álvarez-Bueno, C., Ferri-Morales, A., Torres-Costoso, A. I., Cavero-Redondo, I., & Martínez-Vizcaíno, V. (2019). Pilates Method Improves Cardiorespiratory Fitness: A Systematic Review and Meta-Analysis. *Journal of Clinical Medicine*, *8*(11), 1761.

Filardo, R. D., & Petroski, E. L. (2007). Adult overweight and obesity prevalence by two anthropometric criteria/Prevalencia de sobrepeso e obesidade em homens adultos segundo dois criterios de diagnostico antropometrico. *Motricidade*, *3*(4), 46-55.

Forte, R., De Vito, G., & Figura, F. (2003). Effects of dynamic resistance training on heart rate variability in healthy older women. *Eur J Appl Physiol*, *89*(1), 85-89.

González-Devesa, D., Varela, S., Diz-Gómez, J. C., & Ayán-Pérez, C. (2024). The efficacy of Pilates method in patients with hypertension: systematic review and meta-analysis. *Journal of Human Hypertension*, *38*(3), 200-211.

Gouveia, S. S., de Morais Gouveia, G. P., Souza, L. M., da Costa, B. C., Sousa, G. H. M., Pinho, V. A., Vasconcelos, S. S., Dos Santos Souza, A. T., da Silva Lopes, T., & Pinheiro, L. G. P. (2022). Heart Rate Variability and Respiratory Muscle Strength in Patients With Type II Diabetes Practicing Pilates: A Randomized Clinical Trial. *Current Diabetes Reviews*, *18*(6), 77-84.

Guimarães, G. V., Carvalho, V. O., Bocchi, E. A., & d'Avila, V. M. (2012). Pilates in heart failure patients: a randomized controlled pilot trial. *Cardiovasc Ther*, *30*(6), 351-356.

Gultekin, S. C., Ozcan Kahraman, B., & Kahraman, T. (2024). Cardiorespiratory responses: Pilates compared to different walking speeds in healthy adults. *Irish Journal of Medical Science (1971-)*, *193*(1), 139-147.

Hoseini Niya, S., Vahidian-Rezazadeh, M., & Heidari Mokarrar, H. (2020). The Effects of 8 Weeks Pilates, Walking, and Combined Pilates and Walking on Heart Arrhythmia. *Zahedan J Res Med Sci*, *22*(1).

Joyce, D., & Barrett, M. (2019). State of the science: heart rate variability in health and disease. *BMJ supportive & palliative care*, *9*(3), 274-276.

Ju, M., Zhang, Z., Tao, X., Lin, Y., Gao, L., & Yu, W. (2023). The impact of Pilates exercise for depression symptoms in female patients: A systematic review and meta-analysis. *Medicine*, *102*(41), e35419.

Kanegusuku, H., Queiroz, A. C., Silva, V. J., de Mello, M. T., Ugrinowitsch, C., & Forjaz, C. L. (2015). High-intensity progressive resistance training increases strength with no change in cardiovascular function and autonomic neural regulation in older adults. *J Aging Phys Act*, *23*(3), 339-345.

Liu, J., & Colditz, G. A. (2017). Optimal design of longitudinal data analysis using generalized estimating equation models. *Biometrical Journal*, *59*(2), 315-330.

Markovic, G., Sarabon, N., Greblo, Z., & Krizanic, V. (2015). Effects of feedback-based balance and core resistance training vs. Pilates training on balance and muscle function in older women: A randomized-controlled trial. *Arch Gerontol Ger*, *61*(2), 117-123.

Masroor, S., Bhati, P., Verma, S., Khan, M., & Hussain, M. E. (2018). Heart rate variability following combined aerobic and resistance training in sedentary hypertensive women: A randomised control trial. *Indian Heart J*, *70*, S28-S35.

McCraty, R., & Shaffer, F. (2015). Heart rate variability: new perspectives on physiological mechanisms, assessment of self-regulatory capacity, and health risk. *Global Adv Health Med*, *4*(1), 46-61.

Meeusen, R., Duclos, M., Gleeson, M., Rietjens, G., Steinacker, J., & Urhausen, A. (2006). Prevention, diagnosis and treatment of the overtraining syndrome: ECSS position statement 'task force'. *Eur J Sport Sci*, *6*(01), 1-14.

Molina, G. E., Fontana, K. E., Porto, L. G. G., & Junqueira, L. F. (2016). Post-exercise heart-rate recovery correlates to resting heart-rate variability in healthy men. *Clin Autonomic Res*, *26*(6), 415-421.

Perini, R., & Veicsteinas, A. (2003). Heart rate variability and autonomic activity at rest and during exercise in various physiological conditions. *Eur J Appl Physiol*, *90*(3), 317-325.

Rayes, A. B. R., de Lira, C. A. B., Viana, R. B., Benedito-Silva, A. A., Vancini, R. L., Mascarin, N., & Andrade, M. S. (2019). The effects of Pilates vs. aerobic training on cardiorespiratory fitness, isokinetic muscular strength, body composition, and functional tasks outcomes for individuals who are overweight/obese: a clinical trial. *PeerJ*, *7*, e6022.

Rezk, C., Marrache, R., Tinucci, T., Mion, D., & Forjaz, C. (2006). Post-resistance exercise hypotension, hemodynamics, and heart rate variability: influence of exercise intensity. *Eur J Appl Physiol*, *98*(1), 105-112.

Rocha, J., Cunha, F. A., Cordeiro, R., Monteiro, W., Pescatello, L. S., & Farinatti, P. (2020). Acute effect of a single session of pilates on blood pressure and cardiac autonomic control in middle-aged adults with hypertension. *J Strength Cond Res*, *34*(1), 114-123.

Roh, S. Y. (2016). Effect of a 16-week Pilates exercise program on the ego resiliency and depression in elderly women. *J Exerc Rehab*, *12*(5), 494.

Sanchis-Soler, G., Tortosa-Martinez, J., Sebastia-Amat, S., Chulvi-Medrano, I., & Cortell-Tormo, J. M. (2024). Is Acute Lower Back Pain Associated with Heart Rate Variability Changes? A Protocol for Systematic Reviews. Healthcare,

Sandercock, G., Bromley, P. D., & Brodie, D. A. (2005). Effects of exercise on heart rate variability: inferences from meta-analysis. *Med Sci Sports Exerc*, *37*(3), 433-439.

Siri, W. E. (1956). Body composition from fluid spaces and density: analysis of methods.

Strüven, A., Holzapfel, C., Stremmel, C., & Brunner, S. (2021). Obesity, nutrition and heart rate variability. *International journal of molecular sciences*, *22*(8), 4215.

Tarnas, M., Marszałek, A., Kufel-Grabowska, J., Marszałek, S., Wieliński, D., & Zieliński, J. (2024). Effects of Pilates Training on Cardiorespiratory Functions in Medical Conditions-Comprehensive Approach: A Narrative Review. *Aging and Disease*, *15*(4), 1771.

Tinoco-Fernández, M., Jiménez-Martín, M., Sánchez-Caravaca, M. A., Fernández-Pérez, A. M., Ramírez-Rodrigo, J., & Villaverde-Gutiérrez, C. (2016). The Pilates method and cardiorespiratory adaptation to training. *Res Sports Med*, *24*(3), 266-271.

Tomasi, J., Zai, C. C., Pouget, J. G., Tiwari, A. K., & Kennedy, J. L. (2024). Heart rate variability: Evaluating a potential biomarker of anxiety disorders. *Psychophysiology*, *61*(2), e14481.

Yoo, K.-T. (2022). Effects of Mat Pilates on the Autonomic Nervous System in the Elderly Women. *Korean Society of Physical Medicine*, *17*(4), 27-35.