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The Effects of a Marathon Effort on Psychomotor Performance and Catecholamine Concentration in Runners over 50 Years of Age

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Abstract: Long-distance running and, in particular, running marathons has become an increasingly popular activity among the elderly. The aim of the study was to examine the effects of a marathon effort on the psychomotor performance and catecholamine concentration in runners over 50 years of age. The participants were male runners (n = 28) who completed the 32nd Wrocław Marathon in Poland. The runners' psychomotor performance was assessed on the basis of their choice reaction times (CRT), heart rate (HR) and running speed measurements. In addition, the adrenaline (A) and noradrenaline (NA) as well as lactate (LA) levels and anaerobic threshold (AT) were measured. The runners' CRT after crossing the finish line was significantly longer by 50 ms ($p < 0.05$) in response to each emitted audiovisual stimulus, as compared with baseline. The mean running speed was reduced by 1 km/h between the first speed measurement (5th km of the run) and the last (42.195 km) ($p < 0.05$). The observed three-fold increase in adrenaline and noradrenaline levels indicates an intense activity of the sympathetic–adrenergic system. The cognitive function levels in the studied marathon runners returned to baseline after 30 min of recovery, and the function of the sympathetic–adrenergic system by seven days after completing the marathon race.

Keywords: marathon; aging; choice reaction time; adrenaline; lactate; heart rate

1. Introduction

Long-distance running and, in particular, running marathons has become an increasingly popular activity among the elderly. Lepers and Cattagni [1] noted a regular increase in the participation of men and women over 50 years of age in the New York City Marathon in the years 1980–2009. This age group also features a significantly more dynamic improvement in sports results than their younger counterparts [2]. In amateur and professional athletes aged 50–60 years the level of endurance skills and psychomotor performance becomes reduced, which is associated with aging-related physiological changes. Studies reveal a reduced VO_2max with age, while the lactate threshold as % of VO_2max and running economy remain mostly unchanged [3,4]. Research shows that an average marathon runner

runs at the intensity of 75%–84% VO_2max, which corresponds to 80%–90% HRmax, and 2–3 mmol/L of blood plasma lactate [5]. While reference to the concentration of lactate (LA) represents one of the most precise ways of determining the anaerobic threshold and assessing fatigue, its measurement as somebody runs a marathon is not feasible [6]. Moreover, data on lactate concentrations in over-50s runners who have just completed a marathon are lacking.

During a marathon race, peripheral and central fatigue develop. In natural conditions, peripheral fatigue never occurs in isolation but is always accompanied by central fatigue [7,8]. Central fatigue during long-lasting exercise is associated with the metabolism and synthesis of monoamines, mainly adrenaline, noradrenaline, dopamine, and serotonin [9]. The secretion of catecholamines depends on the duration and intensity of physical exercise, and it significantly determines the sympathetic–adrenergic response [10]. Long-lasting exercise at 70% of threshold intensity involves a gradual increase in catecholamine blood concentration with time [10,11]. Hodgetts et al. [10] showed that low-intensity exercise (30% VO_2max) led to a rise in the level of catecholamines, not exceeding the noradrenaline (NA) and adrenaline (A) thresholds even during periods of exercise longer than 240 min. These two thresholds reflect burdening in relation to stress, and their crossing is followed by an abrupt rise in the NA concentration (9.38 ± 1.33 nmol·L^{-1}), as well as that of adrenaline (1.50 ± 0.21 nmol·L^{-1}), in blood plasma [12]. It is also interesting that increased catecholamine concentration co-occurs with improved reaction times during moderate-intensity exercise of 60 minutes' duration [11].

Reaction time is commonly regarded as an indicator of the level of central fatigue and psychomotor performance [13–15]. Some authors state that reaction time becomes longer under fatigue [16]; others claim, contrary to popular belief, that they become shorter [17]. These discrepancies probably result from the fact that participants in those studies performed exercise tests of differing character, in which the mechanism of fatigue generation was not uniform [16,18]. Chmura and Nazar [13] revealed that changes in psychomotor indices during incremental exercise are threshold–related, and are associated with the level of activation of the central nervous system. The course of the changes is linked to the Psychomotor Fatigue Threshold (PFT), i.e., the upper limit of exercise fatigue and fatigue tolerance accompanied by the shortest reaction time, the highest level of differentiation between audiovisual stimuli and most optimal decision-making. Crossing the PFT leads to a rapid deterioration in these variables [13].

The shortest reaction time is reached around the age of 25–35 years [19]. After that it declines, though regular sports training may prevent some degenerative changes in the brain from occurring. At the age of 60 physically active individuals demonstrate higher psychomotor performance levels than non-training individuals [20–23]. The relationship between physical activity and cognitive function is based on processes connected with cerebral perfusion (the so-called aerobic hypothesis) and on the activity of selected neurotrophic factors stimulating higher layers of the brain [23,24].

There have been studies on changes in psychomotor performance during exercise of incremental intensity, exercise with threshold loads (below and above the anaerobic threshold) as well as on the level of performance after exercise completion [11,12,25,26]. Meta-analyses by Brisswalter et al. [25] and Tomporowski [26] revealed that physical exercise of moderate intensity can improve psychomotor performance, whereas hard physical labor may reduce the efficiency of cognitive processes. There are no studies on how long-distance running influences elderly individuals' psychomotor performance or adrenaline and noradrenaline levels. It is also unknown if elderly individuals exhibit a similar relationship between the two as do their younger counterparts. The aim of the study was to examine the effects of a marathon effort on the psychomotor performance and catecholamine concentration in runners over 50 years of age.

2. Materials and Methods

2.1. Participants

The participants were male runners (n = 28) who had completed the 32nd Wrocław Marathon in Poland, and were aged 58 ± 8 years, body mass 75 ± 11 (kg), with a body height of 174 ± 7 (cm). The participants were recruited in line with the following criteria: age above 50 years, completion of one marathon, and no cardiological history [27]. Table 1 shows the mean values of physiological variables attained during an incremental treadmill test, 14 days before a marathon race. The study was conducted in compliance with the Declaration of Helsinki and was approved by the local ethics committee. The study protocol was also approved by the Local Board of Ethics.

Table 1. Physiological variables measured during an incremental treadmill test.

VO_2max (mL·kg^{-1}·min ^{1})	HRmax (Beats·min^{-1})	HRAT (Beats·min^{-1})	HRAT (% HRmax)	VE Max (L·min^{-1})
mean ± SE				
51 ± 2	170 ± 2	153 ± 2	90 ± 1	144 ± 4

HRAT—heart rate anaerobic threshold.

2.2. Weather Conditions and Route Profile during the Marathon Race

The marathon race took place between 9 a.m. and 3 p.m. During the run the mean air temperature was 21.48 ± 2.14 °C, with relative air humidity of 76.85 ± 13.23% and a partly cloudy sky. The air temperature and humidity measurements were taken on the hour at a weather station of the Polish Institute of Meteorology and Water Management – National Research Institute in Wrocław (IMGW–PIB).

The profile of the Wrocław Marathon route was flat. The maximum difference was 10 m. The lowest point was 114 m above sea level at 10 km of the route, while the highest point was 124 m above sea level at 33 km of the route (www.wroclawmaraton.pl).

2.3. The Indoor Treadmill Test

Fourteen days before the marathon, the participants performed a treadmill test following the study protocol after Bruce [28], and thus consisting of running at incremental intensity until refusal. The test was performed on a TMX TRACKMASTER treadmill (Newton, KS, USA,). In the first three minutes, the participants were running at 2.7 km/h and at the incline degree of 10°. Further loads were added subsequently, according to the protocol. Heart rate (bpm^{-1}) was measured with an M400 sport tester (POLAR, Vantaa, Finland). Oxygen uptake VO_2 (L·min^{-1}) and respiratory minute volume VE (L·min^{-1}) were measured during exercise and for 5 min of recovery. The pulmonary respiration components were assessed using an Ergostick apparatus (Reynolds Medical, San Antonio, TX, USA). The anaerobic threshold (AT) was marked on the basis of sudden non-linear increases in pulmonary ventilation at a high exercise intensity [29]. The research procedure is presented in Figure 1.

2.4. Psychomotor Test—Choice Reaction Time

Psychomotor performance was assessed on the basis of choice reaction time (CRT) measurements with the use of the APR reaction measuring instrument (UNI-PAR, Warsaw, Poland). The program was the same for each subject and consisted of 15 audiovisual stimuli: 10 stimuli to react to (4 sound stimuli, 6 red light stimuli), and 5 visual stimuli to not react to (2 yellow lights and 3 green lights). Before each CRT measurement, each participant was given the measuring apparatus with a thumb button. When the apparatus emitted a red light, a participant was to press and release the button with the right thumb, and when a sound was emitted, with the left thumb, as quickly as possible. The participants were not to respond when the apparatus emitted a yellow or a green light. The test was carried out in a sitting position of 1.5 m in front of the screen, in line with the procedures described

by Chmura et al. [12]. The participants' CRT was measured at rest, and 1 min, 30 min, and 7 days after the completion of the marathon.

2.5. Heart Rate and Running Speed during the Marathon Race

Heart rate was measured during the marathon run (HR bpm^{-1}) with the use of a Polar M400 running watch (Finland). The mean HR values measured after 5, 10, 15, 21.097, 30, 35, 40 and 42.195 km, as well as after the completion of the run were analyzed. Furthermore, the mean running speed (km/h) was measured on the mentioned lengths of the running distance.

2.6. Catecholamine levels

Before the start, immediately after crossing the finish line, and 7 days after the marathon race, blood samples were drawn from the runners' ulnar vein to measure the adrenaline (A) ($nmol \cdot L^{-1}$) and noradrenaline (NA) ($nmol \cdot L^{-1}$) blood plasma concentrations. The levels of adrenaline and noradrenaline measured immediately after the marathon were taken as corresponding to the levels of these hormones at the end of the exercise test. The A and NA concentrations were assessed with radioimmunoassays in the plasma samples (EDTA), following their extraction and acylation. The hormonal levels were marked with the use of 2-CAT RIA commercial kits (DIAsource Immunoassays S.A., Ottignies-Louvain-la-Neuve, Belgium), using a Wallac Wizard 1470 gamma counter.

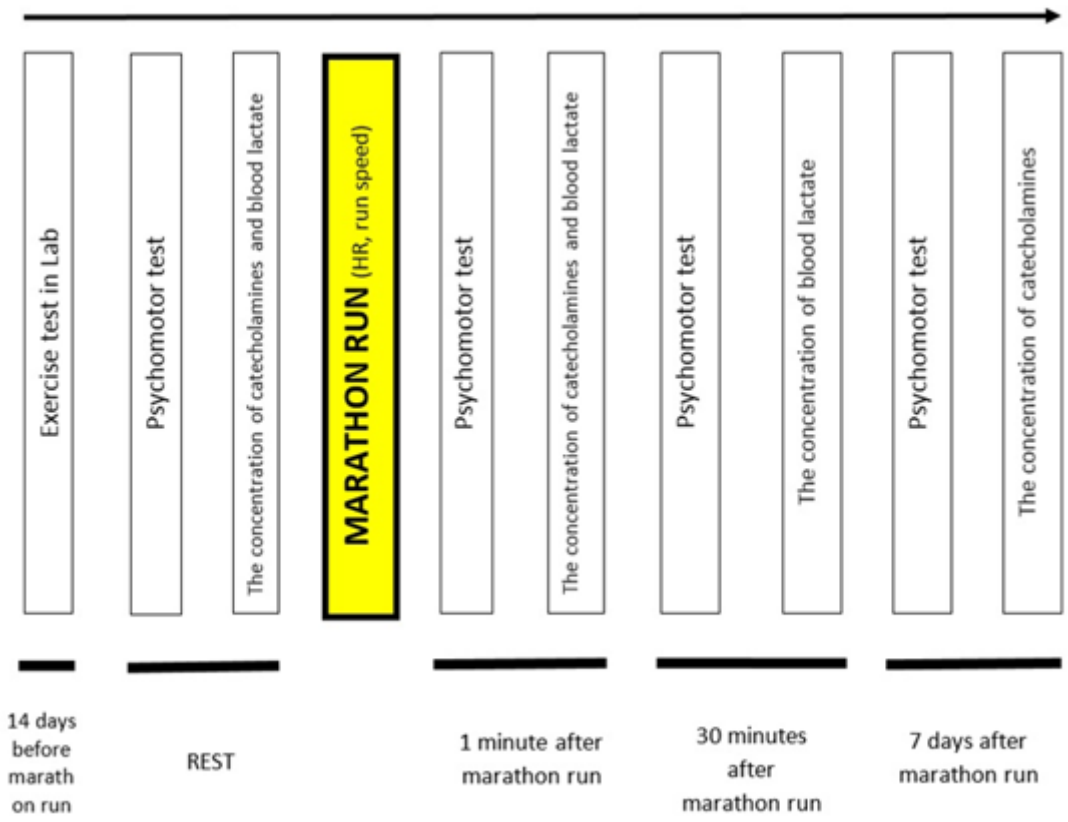

Figure 1. Diagram of measurements.

2.7. Lactate Concentration Measurements

The runners' arterialized blood was drawn from the fingertip at rest (60 min before the start of the marathon), as well as 1 min and 30 min after the finish, for lactate (LA) concentration measurement ($mmol \cdot L^{-1}$) using the enzymatic–amperometric method (Lactate Scout, SensLab GmbH, Leipzig, Germany) with a measuring range between 0.5 and 25 mmol/L. The measurement duration was about 10 s, and the blood sample volume was 0.5 µL.

2.8. Statistical Analysis

Continuous variables with normal distribution were presented as mean ± standard error (mean ± SE). Categorical variables were presented as numbers and percentages. For continuous variables, intergroup differences were compared using repeated measures ANOVA (CRT, running speed, HR) and the Mann-Whitney U test (A, NA, LA). The χ^2 test was used to compare categorical variables. The levels of statistical significance were set at $p \leq 0.05$. All statistical analyses were performed using the Statistica 13.0 software (StatSoft, Tulsa, OK, USA).

3. Results

The marathon runners over 50 years of age completed the race at the mean time of 257.00 ± 10.51 min, i.e., 4 h 17 min.

3.1. Psychomotor Test—Choice Reaction Time

The choice reaction time (CRT) measured immediately after completion of the race was significantly longer ($p < 0.05$), by 50 ms on average, in response to each emitted audiovisual stimulus, as compared with the baseline. The CRT was significantly shorter 30 min after the end of the marathon than after 1 min of recovery ($p < 0.05$). On the 7th day after the marathon the CRT was at a similar level to the measurement 30 min after the finish. After 30 min the CRT was 10 ms longer, and after seven days, 13 ms longer than at rest. These differences were non-significant statistically (Figure 2).

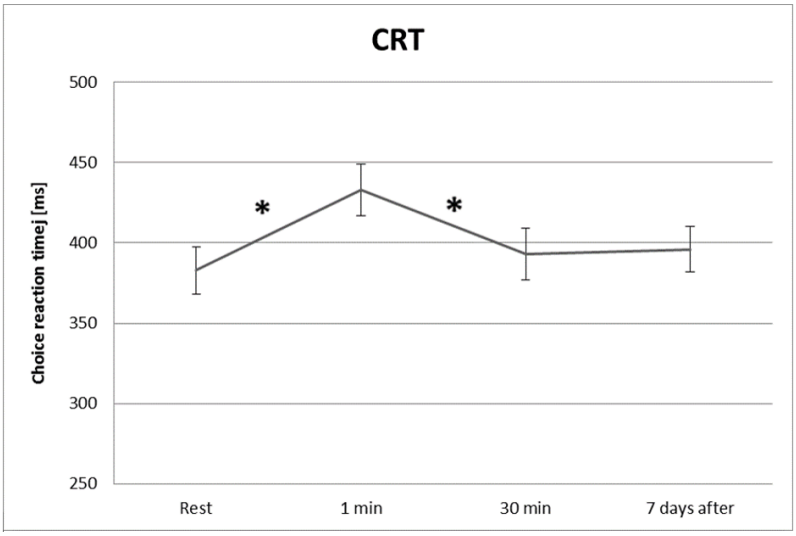

Figure 2. Changes in choice reaction time before and after a marathon exercise (mean ± SE). Statistically significant differences: * ($p < 0.05$).

3.2. Heart Rate and Running Speed during the Marathon Race

The heart rate in marathon runners over 50 years of age rose significantly between 10 km and 15 km ($p < 0.05$) (Figure 3). Between 15 km and 25 km it was relatively stable, and then decreased at 30 km ($p < 0.05$). Over the next 10 km, no significant changes in HR were noted, and the mean HR was close to the 5 km and 10 km levels. During the entire race the most marked HR increase (by an average of 8.1 bpm) was noted between 40 km and the completion of the marathon ($p < 0.05$) (Figure 3). The mean HR was 150 ± 2 bpm, and HR max 163 ± 2 bpm. The mean running speed decreased steadily after 5 km, at each subsequent time measurement until the finish. The lowest decrease in running speed was noted up to the first 10 km (by about 0.04 km/h). The decrease in mean running speed between the first and the last measurements amounted to 1 km/h ($p < 0.05$) (Figure 3).

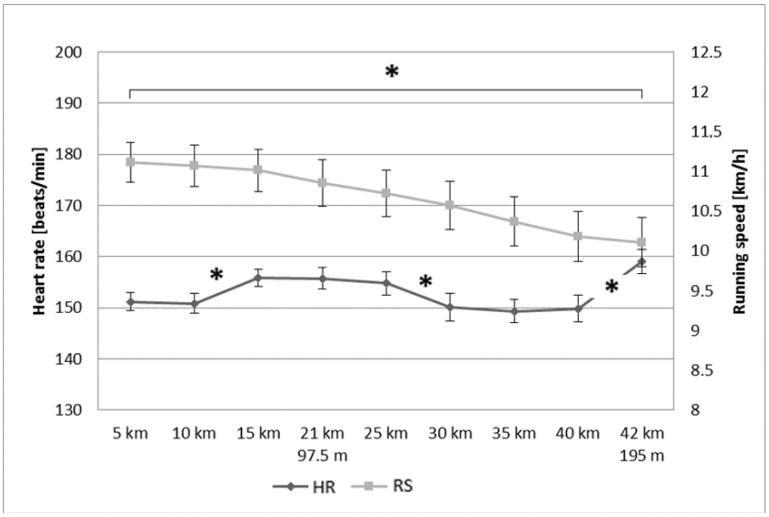

Figure 3. Changes in heart rate (beats/min) and running speed (km/h) during a marathon (mean ± SE). Statistically significant differences: * ($p < 0.05$).

3.3. Catecholamine and Lactate Levels

A significant increase ($p < 0.05$) in adrenaline plasma concentration was noted after 1 min of recovery as compared to baseline. Seven days after the completion of the marathon the adrenaline level had decreased significantly ($p < 0.05$) and was close to the resting levels. In addition, the mean noradrenaline level after 1 min of recovery was significantly higher than the pre-exercise levels ($p < 0.05$). After seven days of recovery the noradrenaline level was significantly lower ($p < 0.05$), and was close to the resting levels. The course of changes in the levels of both hormones was similar (Table 2).

Table 2. Catecholamine levels in plasma before and after the marathon race.

Catecholamine	Rest (R)	After the Marathon		Statistical Significance ($p < 0.05$)
		1st Min (AM)	7th Day (A7)	
		mean ± SE		
Adrenaline (nmol·L^{-1})	0.25 ± 0.02	0.89 ± 0.10	0.24 ± 0.03	R vs. AM AM vs. A7
Noradrenaline (nmol·L^{-1})	1.89 ± 0.13	6.33 ± 0.32	1.78 ± 0.20	R vs. AM AM vs. A7

A significant increase in lactate concentration was noted between the resting level and the value 1 min after the end of the run ($p < 0.05$). After 30 min of recovery the lactate level was significantly lower ($p < 0.05$), but it was still higher than at rest ($p < 0.05$) (Table 3).

Table 3. Lactate level changes before and after the end of the marathon.

Lactate (mmol·L^{-1})			Statistical Significance ($p < 0.05$)
Rest (Baseline)	After the Marathon (Post-Exercise)		
(LA_R)	1 Min (LA 1′)	30 Min (LA 30′)	
	mean ± SE		
1.67 ± 0.05	3.83 ± 0.35	2.77 ± 0.16	LA_R vs. LA 1′ LA 1′ vs. LA 30′ LA_R vs. LA 30′

4. Discussion

A marathon run induces significant changes in the levels in psychomotor performance and blood plasma catecholamines in men over 50 years of age. The results of the present study indicated a decrease in psychomotor performance immediately after the marathon finish in comparison to its pre-exercise level. The choice reaction time was 50 ms longer for each audio-visual stimulus. A reduced level of psychomotor performance after a long-term exercise was confirmed by a number of authors [25,26,30]. However, there have been no studies on changes of psychomotor performance and catecholamine levels in male 50-year-old marathon runners.

The results of the present study revealed significant increases in the adrenaline level by 356% to 0.89 ± 0.10 (nmol·L^{-1}) and the noradrenaline level by 334% to 6.33 ± 0.32 (nmol·L^{-1}), in the last phase of the marathon race compared to the baseline at rest. The changes in the concentration of these hormones indicate a high level of activation of the sympathetic-adrenergic system. Despite the three-fold increase in catecholamine levels in the present study a deterioration, rather than an improvement, in psychomotor performance was noted. These data had not been confirmed in earlier studies. Some previous studies revealed the shortest choice reaction time concurrently with the rapid rise in plasma catecholamines after crossing the 4 mmol onset of blood lactate accumulation threshold (OBLA), and then the adrenaline and noradrenaline thresholds, during incremental endurance exercise [12]. This shows that the optimal activation level of the central nervous system for processing signals during choice reaction measurements is reached once the catecholamine threshold has been crossed. This fact can be seen as confirmed by the clear correlation between choice reaction time and blood-plasma concentrations of adrenaline (r = 0.93) and noradrenaline (r = 0.94) [12]. The mean A (0.89 ± 0.10 nmol·L^{-1}) and NA (6.33 ± 0.32 nmol·L^{-1}) levels in runners over 50 years of age were significantly lower than adrenaline and noradrenaline threshold levels during progressive exercise [12,31]. This indicates that, in the final phase of the marathon race, the studied runners failed to attain optimal activation of the central nervous system. However, this does not mean failure to reach this activation level temporarily, during earlier phases of the race.

During a marathon race the most important physiological variable is the anaerobic threshold, since its level directly determines aerobic energy output and the capacity to sustain a steady high running speed [32,33]. The mean heart rate during the marathon race (150.11 ± 1.78 bpm) was lower than the heart rate at the anaerobic threshold (152.50 ± 1.89 bpm) in laboratory conditions. This indicates that, while individual marathon runners may have occasionally crossed the anaerobic or psychomotor fatigue thresholds (e.g., during run-ups, accelerations, or the finish), they were not running steadily for prolonged periods at those thresholds [13]. Maintaining running intensity at an anaerobic threshold over a distance of 42.195 km is impossible due to the development of metabolic acidosis, i.e., accumulation of metabolites responsible for fatigue development [34,35]. The accumulation of hydrogen ions (H+) in muscle cells may produce direct impairment of the contractile function [34,35].

Despite being performed at a mean intensity below the anaerobic threshold, the marathon exercise, up to six hours in duration (from 3:30:39 to 5:54:42), did cause individual high levels of fatigue as it is attested to by lactate concentrations above 4 mmol/L. Manifestations included a steady decrease (on average of 1 km/h for the whole group) in running speed until race completion, and a longer choice reaction time to 10 audiovisual stimuli (by 500 ms in total). The development of fatigue during a marathon race can be determined by a number of factors, which directly affect the function of the central nervous system [7]. During physical exercise longer than 60 min, a disturbance in psychomotor performance can be observed due to dehydration and incremental hyperthermia [18,36,37]. While fluid and food intake during the marathon were not controlled, a mere 2% of dehydration-related body mass loss has a negative impact on psychomotor performance [38]. Furthermore, along with the increase in ambient temperature, the body temperature also rises, reaching even 39–40.5 °C [39]. This rise in body temperature causes a decrease in stroke volume (SV). A mechanism that compensates for this adverse phenomenon is the impact of catecholamines on the acceleration of heart rate, which rises significantly after 35 km of a marathon race, despite a steady decrease in running speed until the end of the race.

The body's recovery after a marathon exercise is crucial. Research shows that the recovery of particular systems of the human body is highly variable, and may last from 3 to 14 days or even a few months [40]. Authors have not provided sufficient evidence about the precise time necessary for restoring homeostasis in the sympathetic–adrenergic and cognitive systems in individuals over 50 years of age. It should be noted that, with age, the process of the body's recovery following a marathon exercise takes more time and is less effective. The noted relatively stable levels of psychomotor performance and sympathetic-adrenergic activity seven days after the marathon (compared to baseline) indicate the restoration of bodily homeostasis. Authors have revealed that the return of the catecholamine levels to baseline varies and depends on the level of fatigue, length of training, and age [41]. Kyrolainen et al. [42] showed that the post-marathon catecholamine level returned to baseline 2 h after the completion of exercise and remained four days after the marathon. Maron et al. [43] noted an elevated adrenaline level from the 2nd day after the end of the marathon, while the concentration of noradrenaline reached its pre-exercise level 24 h after the marathon. It should be emphasized that the mentioned authors did not study marathon runners over 50 years of age, whose responsiveness of the sympathetic system was lower due to age [44–46].

Marathon running consists of a number of highly individualized variables. The limits of the present study were the lack of information about the competitors' supplementation during the race, and the lack of comparisons with other age categories [27,38]. Involving more variables would require a larger test sample [47]. In future studies, the authors plan to consider specific running strategies, which is an important factor influencing the marathon running time [48]. Moreover, runners' experience and performance level should also be taken into account as they vary significantly among competitors over 50 years of age [49].

5. Conclusions

Considering the growing popularity of marathon running among the elderly, this study adds to the current knowledge regarding the effects of a marathon effort on the psychomotor performance and catecholamine concentration in runners over 50 years of age. There have been only a few relevant studies on the impact of physical efforts of a different character on much younger age groups [50]. It is therefore rather difficult to assert whether there is a phase of optimal activation of the central nervous system during a marathon exercise, and which factors negatively affect runners' psychomotor performance. The results of our study indicate that a three-fold increase in the adrenaline and noradrenaline levels during a marathon run did not cause an optimal activation of the central nervous system. This shows that it is the intensity of exercise, and not exercise duration, which determines the optimal activation of the central nervous system. Moreover, the results of the study can contribute to the optimization of marathon training, improvement of runners' safety, and reduction of health risks in long-distance runners over 50 years of age. Further research into runners during a marathon race, or simulated marathon exercise accounting for runners' age and sex, is recommended.

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