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Research Article

Response Variability and Detraining Effects of Standardized Exercise Programs

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Abstract

Purpose: To compare inter-individual response variability and detraining effects on markers attributed to aerobic and anaerobic performance after short-term standardized aerobic, strength and mixed training programs.

Methods: Thirty-six male students were randomly assigned to either an aerobic, strength, mixed, or control program (9 per group). They performed two consecutive cycling tests (incremental and plateau) to exhaustion at three points: 1 week before training, after 6 weeks of training, and 3 weeks after the training was finished. Maximal oxygen consumption (VO_{2max}), maximal workload (W_{max}), and time to exhaustion performed at W_{max} (W × time) were compared between groups by repeated-measures ANOVA with Bonferroni post-hoc tests. The inter-subject response variability within each training group was evaluated by comparison with the 95% confidence interval of the control group. Detraining effects were evaluated using the hysteresis areas, which were compared between each training group and the control group by Mann-Whitney U test.

Results: Differences were observed in W_{max} for the aerobic ($F(2,7)=19.562$; $p=0.001$; $n^2=0.85$) and mixed ($F(2,7)=13.447$; $p=0.004$; $n^2=0.99$) programs, and in W × time for the mixed program ($F(2,7)=15.432$; $p= 0.016$; $n^2=0.89$). There was high inter-subject response variability for all variables and training programs, except for a homogenous positive response to W_{max} in the mixed program ($X^2=6.27$; $p=0.04$). Detraining effects of W_{max} were also better maintained after the mixed program.

Conclusion: A mixed program of aerobic and strength training demonstrated higher improvements in the studied markers of performance, with lower inter-individual response variability, and longer detraining effects compared with aerobic or strength programs.

Keywords: Mixed training; Personal constraints; Aerobic and anaerobic markers; Hysteresis

Abbreviations

AER: Aerobic Training; CI: Confidence Interval; CON: Control Group; HIIT: High-Intensity Interval Training; MIX: Mixed Training; STR: Strength Training; VO_{2max}: Maximal Oxygen Consumption; W_{max}: Maximal Power; W × time: W_{max} Tolerated Per Time.

Introduction

The benefits of physical activity are well recognized, leading to standardized exercise programs being increasingly prescribed to improve health and performance [1]. Their adequate selection claims for empirical evidence and a good understanding of their individual effects, including those at different timescales. However, the effects of Aerobic (AER), Strength (STR), and Mixed (MIX) training programs have only been studied based on their group mean improvements on performance and physiological variables [2], with no meaningful comparison of their inter-individual variability in training response and detraining effects.

Although some individuals show great improvements in performance and physiological markers after short-term exercise programs, others experience little or no change [3]. In addition, a low training response in one performance or physiological marker does not necessary imply a low training response in others [4–7]. This inter-individual response variability has been previously studied for AER and STR training programs. Although sports performance tests can be classified as reduced according to their aerobic or anaerobic metabolic predominance, both systems are present in greater or lesser involvement depending on the characteristics of the tests [8]. Thus, on the one hand, the tests where most of the energy is used to perform the workout comes from aerobic routes, are related to aerobic metabolism. On the other hand, the tests where most of the energy is used to perform the workout comes from anaerobic routes, are related to anaerobic metabolism. Early research using maximal oxygen consumption (VO_{2max}), one of the common and reliable physiological markers of cardiorespiratory performance, indicated variations from almost no gain [3] to a 100% increase in large groups of sedentary individuals after standardized AER training programs [9–11]. STR programs have also been shown to induce inter-individual differences [12], particularly in muscle response [13–15]. However, to our knowledge, inter-individual variability of training responses to MIX programs have not been assessed. The importance of this knowledge gap is emphasized by the fact that MIX programs

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are commonly followed by elite athletes and are widely recommended in a variety of populations, including prepubescent children [16], adults [17], older adults [18], or cardiac rehabilitation patients [19]. Beyond greater adherence, exercise variability has been associated with higher physiological [20] and cognitive adaptations [21], such as motor patterns retention [22].

Three abilities have been identified that explain inter-individual variability in response to exercise: the ability to perform with minimal training, the speed of adaptation or trainability, and the upper achievable limit [23]. These factors have not been causally related to DNA sequence variations, leading Bouchard and Rankinen [10] to observe that pre-training phenotype and contextual aspects may contribute to variability in training response. For instance, age, sex, race, and anthropometric measures can create differences in AER performance [24,25]. Other authors highlight the potential role of psychosocial variables on performance [26]. Given that redundant and degenerate mechanisms operating at the physiological level limit the general utility of reductionist assumptions like genetic 'causation,' complex approaches have been proposed to explain the inter-individual differences in response to training programs [27].

A prominent feature of short-duration standardized programs seems to be the individual rate of adaptation. As Hristovski et al. [28] observed, there is no one-to-one mapping between training dose and effect because training residuals or memory effects play significant roles in neurobiological systems. Figure 1A shows that the relationship between training workload and performance follows a different path during training and detraining phases, the latter being characterized by a less steep trend, whereas Figure 1B shows that the overreaching to the overtraining bifurcation is produced by a small change to the training history.

The historical dependency of neurobiological systems is evidenced by their delay to recover the initial state after a perturbation, also known as the hysteresis phenomenon. This has been investigated in cardiovascular response [29,30], muscle properties [31], and diagnostics [32], and it has recently been proposed as a non-invasive marker of exercise strain and tolerance [33]. Variability in the hysteresis response to standardized programs may therefore reflect different adaptation to strain produced by each type of program, i.e., the detraining effects. As such, detraining should be enlarged in those training programs that combine inputs to provoke higher response variability [34].

In the current research, we aimed to compare the inter-individual response variability and detraining effects to aerobic and anaerobic markers after short-term standardized training programs. We hypothesized that mixed aerobic and strength training can result in higher improvements of aerobic and anaerobic markers of performance, as well as longer detraining effects, in contrast with aerobic or strength training separately.

Methods

Participants

Thirty-six healthy male physical education students agreed to participate in the study (age, 22.6 ± 1.9 years; height, 1.78 ± 0.01 m; body mass, 71.2 ± 0.7 kg; and body mass index, 22.6 ± 1 kg·m^{-2}) (Table 1). The required sample size of 36 was calculated in G*Power 3.1 [35] based on an effect size of 0.28 by Cohen's d, an α of <0.05, and a power (1—β) of 0.95. All participants were recreational sportsmen who did not engage in planned or regular competitive physical activity and who followed no specific or regular training program. The participants were randomly assigned to one of four groups: aerobic exercise training, strength exercise training, mixed aerobic and strength exercise training, and control group. Nine participants were included per group. After reading and signing an informed consent document, they were notified that they could withdraw from the study at any time. Experimental procedures were approved by the Local Ethics Committee and were carried out in accordance with the ethical guidelines laid down in the Helsinki Declaration [36].

Procedure

The following testing procedures were performed one week before the training period and 2–4 days after finishing both the training (i.e., at 6 weeks) and the detraining (3 weeks) periods. All tests were carried out at least 3 hours after a light meal (usual food), at an ambient temperature of 22°C–24°C, and at a relative humidity of 55–65 %. Participants were instructed not to perform any vigorous physical activity for 72 hours before testing. No caffeine or stimulants were previously consumed.

Cycling tests

At each assessment, the participants performed two consecutive cycling tests (incremental and plateau) to exhaustion. The incremental test started at 0 W, with the workload increased by 25 W/min until they were unable to maintain the prescribed cycling frequency of 70 revolutions per minute for more than five consecutive seconds (W_{max}). After 6 min for recovery, the plateau test was carried out maintaining as long as possible the maximal load achieved in the incremental pre-training test (W × time). Respectively, we chose W_{max} and W × time as the performance variables for the incremental and the plateau tests, being W x time chosen as a marker of anaerobic performance because the plateau test involved a maximal intensity exercise performed during less than four minutes. These protocols, incremental and plateau, are used in sports physiology, although, to

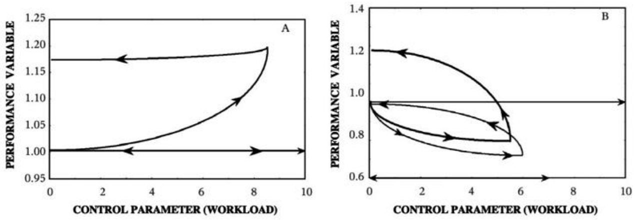

Figure 1: General types of adaptation to training workload. With permission from Hristovski et al. [28].

Table 1: Average anthropometric measures of participants by study group. Data are reported as means and standard deviations.

	Age (years)	Height (m)	Body mass (kg)	BMI (kg/ m^{-2})
AER	23.1 ± 2.3	1.74 ± 0.06	69.5 ± 4.5	22.7± 1.6
STR	22.6 ± 2.4	1.8 ± 0.03	68.8 ± 3.6	21.9 ± 2.6
MIX	23.2 ± 1.6	1.79 ± 0.07	74.1 ± 5.2	23.1 ± 1.4
CON	21.7 ± 0.9	1.78 ± 0.04	72.4 ± 4.8	22.7 ± 1.4

AER: Aerobic training; BMI: body mass index; CON: Control; MIX: Mixed training; STR: Strength training.

our knowledge, they have not been applied together in variability studies. The researcher that carried out the laboratory effort tests, was not aware in which training group each subject was located.

Respiratory gas exchange was assessed as participants breathed through a valve (Hans Rudolph, 2700, Kansas City, MO, USA) with an automated open-circuit system (Metasys, Brainware, La Valette, France). Oxygen (O_2) content, carbon dioxide (CO_2) content, and air flow rate were recorded breath by breath. Before each trial, the system was calibrated with a mixture of O_2 and CO_2 of known composition (15% O_2, 5% CO_2, balanced N_2) (Carburos Metálicos, Barcelona, Spain) and ambient air. VO_{2max} in the incremental test was used as a physiological variable. An Electrocardiogram (ECG) was monitored continuously (CardioScan v.4.0, DM Software, Statelin, Nevada, USA).

Training programs

Participants followed their assigned specific training program three times/week for six weeks. Each session lasted 60 min. The program details were as follows:

- AER: cycling at 60% of the participant's W_{max}.
- STR: a 10-workstation strength circuit that alternated upper and lower body exercises over 30 min. The circuit was carried out twice. The prescribed weights allowed them to perform a maximum of 12 repetitions with 2 min rests between sets. Each repetition was checked to ensure a slow controlled movement (2 s up and 4 s down), with one full inspiration and expiration, and without breath holding (Valsalva maneuver). Starting weights were 40% of one repetition maximum for the upper body (i.e., chest press, pull down, triceps extension, biceps curl and shoulder press) and 60% for the lower body (i.e., squat, calf raise, quadriceps extension, leg curl and leg press). If the participants could comfortably lift the weight for up to 12 repetitions, the weights were increased by 5% for the next training session [37].
- MIX: 30 min of one strength circuit (see STR) followed by 30 min cycling (see AER).
- CON: no modifications were made to the usual activities of students, who were asked to continue their normal exercise routine.

All training sessions were supervised and workloads were adjusted weekly, with resistance increased by 5% if the participant could lift the weight comfortably (i.e., >12 repetitions). During the post-training period (three weeks of detraining), all participants returned to unmodified habitual activities with no special training.

Statistical analysis

Descriptive data, W_{max}, VO_{2max} and W × time were reported as means and standard deviations. Kolmogorov–Smirnov test was applied to demonstrate a normal distribution. Repeated-measures ANOVA, with the Bonferroni post-hoc test to evaluate paired differences, was used to compare the mean results obtained for each group in the pre-training, post-training, and detraining evaluation periods. One-way ANOVA was performed to evaluate preliminary between-group differences in age, height, body mass, and body mass index.

The inter-individual response variability within each training group was evaluated by comparing the 95% Confidence Interval (CI) of the CON group with that of the other three groups, as follows: increments (upper 95% CI values), maintenance (95% CI values), and decrements (lower 95% CI values) [38]. Changes between the three evaluation periods were then assessed by chi-square tests.

To evaluate detraining effects of each training group, we measured the hysteresis area of W_{max}, VO_{2max}, and W × time as the area formed between the evaluation results (pre-training to post-training, and post-training to detraining). According to Montull et al. [33], prior to calculation of hysteresis area, data points were rescaled from 0 to 10, with 10 being the highest value of each group x variable, in order to observe equivalent areas. The area was considered positive if detraining values were higher than the pre-training values, and this was taken to indicate detraining effects; the reverse was considered negative [33,39]. Finally, the values conforming the areas of AER, STR and MIX were compared with the CON group using the Mann–Whitney U matched test, after demonstrating their non-normal distribution using a Kolgomorov-Smirnov test. All analysis set the significance level at p<0.05 and were performed using SPSS v.15 (SPSS Inc., Chicago, USA) and MATLAB (The MathWorks Inc., Natick, MA, USA).

Results

Mean group values

Table 2 summarizes the performance and physiological results (mean ± SD) in each group for the incremental and plateau tests. Differences among the three testing periods were only found between the AER and MIX groups for W_{max} (AER: $F(2,7)=19.562$; $p=0.001$; $n^2=0.85$; MIX: $F(2,7)=13.447$; $p=0.004$; $n^2=0.99$) and W ×

Table 2: Average performance and physiological variables for each group in the incremental and plateau tests. Data are reported as means and standard deviations.

		Incremental test		
		Pre-training	**Post-training**	**Detraining**
W_{max}	AER[a,b]	290 ± 40	323 ± 46	304 ± 46
	STR	279 ± 27	287 ± 31	283 ± 31
	MIX[a,b,c]	261 ± 27	292 ± 22	291 ± 22
	CON	293 ± 33	291 ± 35	290 ± 35
VO_{2max} (ml/min/kg)	AER	52.03 ± 8.3	50.6 ± 9.3	57.63 ± 8.6
	STR	48.16 ± 4.7	46.9 ± 5.8	51.2 ± 5
	MIX	44.96 ± 4.7	52.66 ± 7.8	52.71 ± 7.9
	CON	47.43 ± 8.2	51.01 ± 5	51 ± 5.6
		Plateau test		
		Pre-training	**Post-training**	**Detraining**
W × time (sec)	AER	50,700 ± 14,944	59,225 ± 11,070	53,732 ± 15,360
	STR	47,729 ± 9,655	52,620 ± 10,295	43,647 ± 7,274
	MIX[a,b]	44,751 ± 12,977	46,973 ± 11,759	47,039 ± 15,150
	CON	49,401 ± 12,671	51,122 ± 12,896	50,801 ± 12,689

[a]Statistical differences in a group along the three evaluation tests.
[b]Statistical differences between pre-training and post-training results.
[c]Statistical differences between pre-training and detraining results.
AER: Aerobic Training; CON: Control Group; MIX: Mixed Training; STR: Strength Training; W_{max}: Maximal power; VO_{2max}: Maximal Oxygen Consumption; W × time: W_{max} Tolerated Per Time.

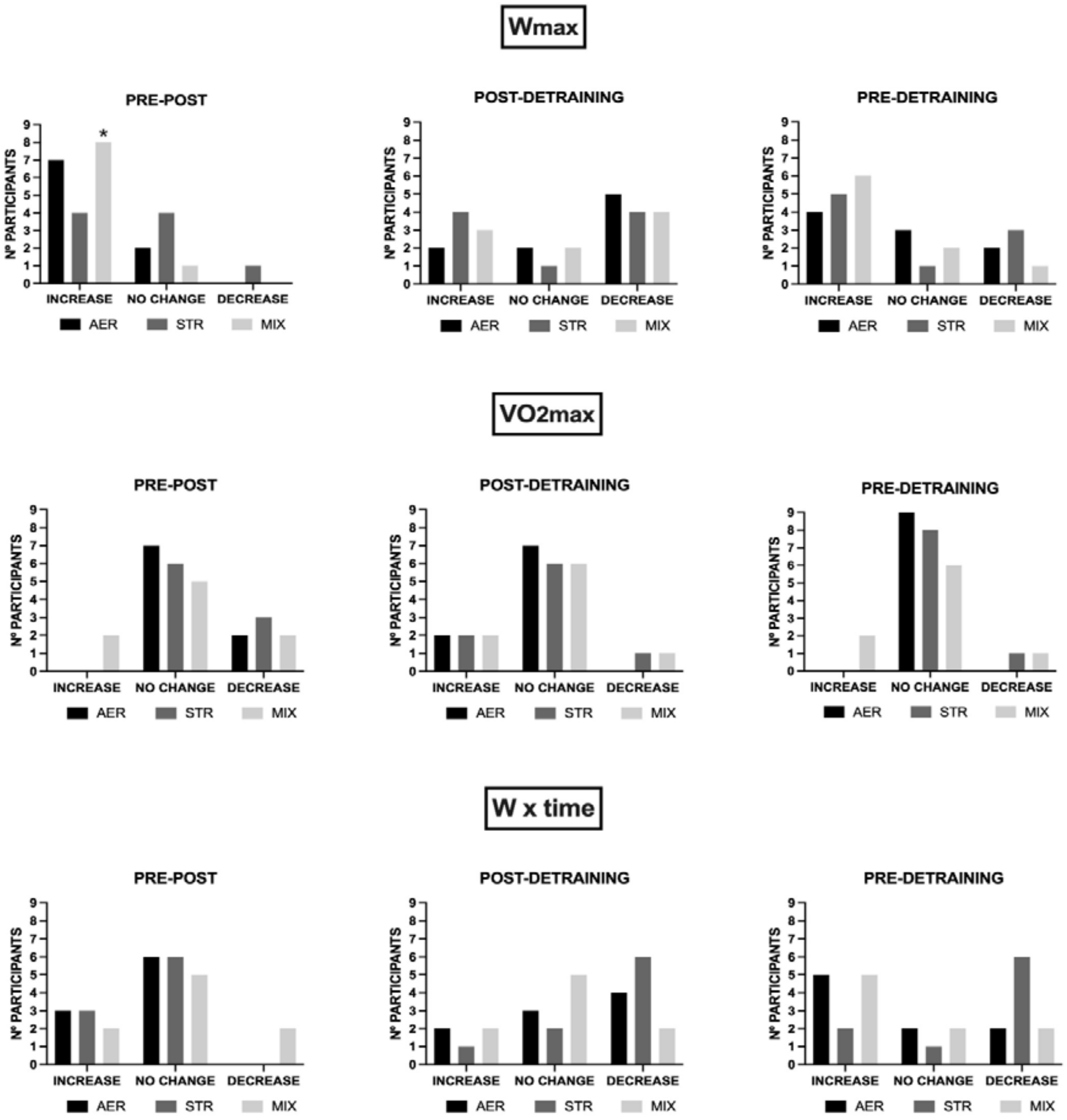

Figure 2: Response variability of the studied performance and physiological variables in the three different experimental groups after training and detraining. Comparisons are based on the control group confidence interval *(p<0.05). AER: Aerobic training, MIX: Mixed training, STR: Strength training, W_{max}: Maximal power, VO_{2max}: Maximal oxygen consumption, W × time: W_{max} tolerated per time.

time (MIX: F(2,7)=15.432; p=0.016; n^2=0.89). Pairwise measures showed improved W_{max} in the AER and MIX groups after training, and between the pre-training and detraining points in the MIX group (p<0.05). The W × time only improved after training in the MIX group (p<0.05).

Response variability

As shown in Figure 2, all registered variables in the AER and STR groups showed high inter-individual response variability to training, whereas the MIX group presented a homogeneous response in W_{max} between evaluations (increases were seen in eight participants) (X^2=6.27; p=0.04).

Detraining effects

Figures 3, 4, and 5 show the hysteresis areas of W_{max}, VO_{2max}, and W × time in each studied group. Notably, the MIX group showed a larger hysteresis area for W_{max} (U=18; p=0.047), indicating a larger effect, compared with the CON group.

Discussion

We reported three main findings from this study. First, training affected aerobic and anaerobic markers in the AER and MIX programs, but not in the STR program. Second, all variables and training programs showed high inter-subject response variability, with the exception of the MIX program, which showed a positive homogenous response in the W_{max} variable. Third, the MIX program showed higher maintenance of detraining effects in the W_{max} compared with either the AER or the STR programs.

Effective training processes are considered those providing an

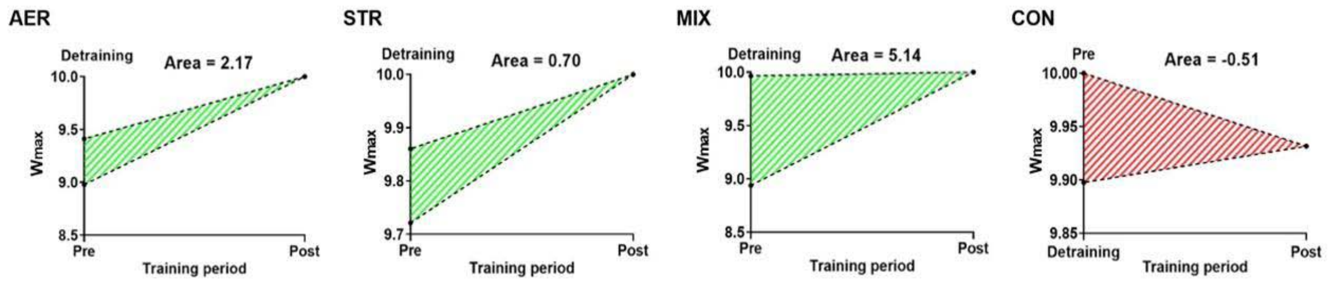

Figure 3: Hysteresis area for W_{max} in the incremental test shown by study group. Positive = green; negative = red. AER: Aerobic training, CON: Control group, MIX: Mixed training, STR: Strength training, W_{max}: Maximal power.

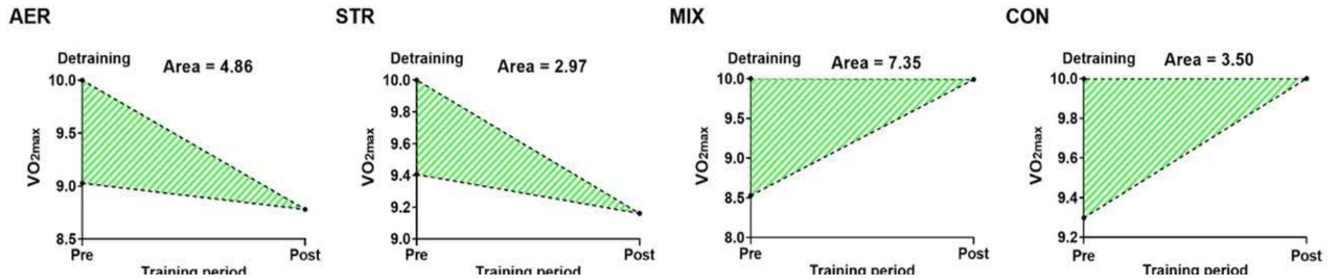

Figure 4: Hysteresis area for VO_{2max} in the incremental test shown by study group. Positive = green; negative = red. AER: Aerobic training, CON: Control group, MIX: Mixed training, STR: Strength training, VO_{2max}: Maximal oxygen consumption.

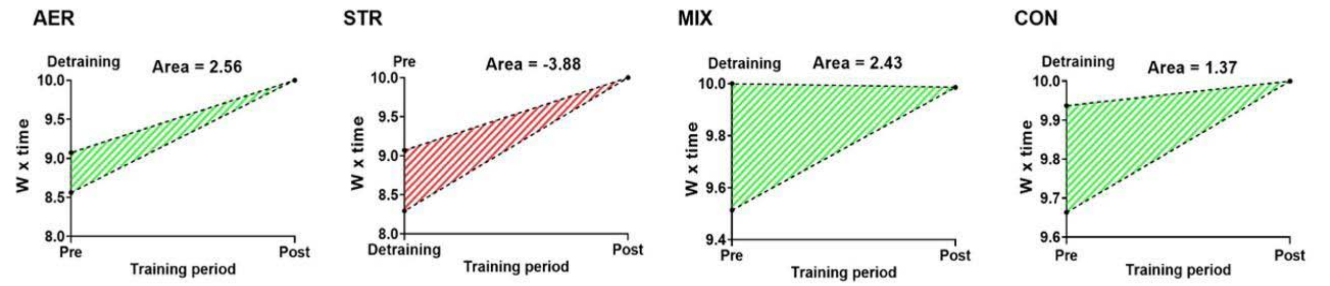

Figure 5: Hysteresis area for W × time in the plateau test shown by study group. Positive = green; negative = red. AER: Aerobic training, CON: Control group, MIX: Mixed training, STR: Strength training, W × time: W_{max} tolerated per time.

input that can be manipulated to elicit a desired training response [40,41]. According to our results, the MIX program showed higher effectivity than the AER program, and even more so than the STR program. The MIX program not only improved aerobic power and anaerobic performance in most participants, but also retained better the training effects, as shown by the higher values obtained after detraining.

Research has suggested that AER training programs, widely applied to cardiac patients, older adults, and athletes, improved not only the adaptations of metabolic, cardiovascular, and pulmonary responses to exercise, but also their coordination [42]. MIX programs add to the benefits of AER training, which provides an intense neuromuscular stimulus that has proven efficacy in endurance [3]. In MIX training, the moderate intensity and training volume leads to synergistic effects, promoting not only strength and endurance gains but also improvements in basal metabolic rates, insulin sensitivity, glucose/lipids metabolism, lipidemic profile, and body composition [1,43–45]. The variety of effects produced by the MIX training, compared to AER and STR, can be explained by the higher variety of exercises that shape this type of training program. As such, MIX training may promote further connectivity among physiological and organ systems, when compared with either AER or STR programs alone. This higher connectivity among organs, that can be measured through the number and strength of couplings among them, has recently been acknowledged as a hallmark of the physiologic state and function by the conceptual frameworks of network physiology of exercise and network medicine [46–48]. Therefore, such couplings become essential to respond to training workloads and to generate distinct adaptation functions. In these frameworks, health and fitness attributes are characterized by the dynamic stability of the organism, which is the result of a reach connectivity and good synergetic communication among physiological systems. This may explain those who are better able to perform well with minimal training, who adapt faster to training, and who have higher upper limits [23]. These abilities may have positively affected the aerobic and anaerobic tests when evaluating training efficacy in this study. When the physiological network is functional, it is rapidly adaptive to perturbations produced by different types of exercise. In contrast, when the physiological network connectivity is poor, disbalanced or overexpressed the adaptivity and dynamic stability of the organism perturbed by exercise may be impaired [48].

STR training, by contrast, produced a more moderate training effect on W_{max} and W × time and produced no positive effect on VO_{2max}. The lack of specificity of the training exercises with respect to the test demands could explain these results. In addition, the previous fitness statuses of participants, combined with the short training period, may also explain some of the negative results [49,50]. Nevertheless, the possible higher variability of training exercises in the MIX program may be key to its higher efficacy in the development and maintenance of aerobic and anaerobic markers. In fact, exercise variability has been associated with faster adaptation, effectivity, and retention of motor patterns than more repetitive methodologies [22].

The observed high response variability to AER and STR training programs that we found is consistent with previous reports. For example, these have shown marked individual differences in responsiveness to standardized endurance training [11] and in muscle response to strength training [44]. However, several putative factors have not been shown to predict trainability [51–55], with a lack of strong evidence of genetic associations with exercise response [56] indicating that research should focus on epigenetics [57]. Despite the many anthropometric similarities, participants may differ in other personal factors, ranging from social to genetic, that act at different timescales [26]. The top–down and bottom–up interactions among environmental, sociocultural, physiological, and psychological contexts on cellular and organ function networks may explain the different abilities of participants [58]. Under the complex systems framework, task performance is understood to be an emergent product from the interaction between personal and environmental constraints [26]. Some constraints are fairly stable (e.g., personal values and motivation) and remain constant during training and detraining periods, affecting the trainability properties. By contrast, others may change at a faster rate (e.g., fatigue and mood) and explain the high biological variability when testing aerobic metabolism [59]. In fact, while lab tests can keep environmental constraints under a degree of control, personal constraints acting at short timescales (e.g., motivation and fatigue) may account for much of the variability.

Contrasting with the AER and STR programs, response variability to the MIX program was much lower. All but one participant improved after training, meaning that despite different personal constraints, the MIX program effectively improved aerobic and anaerobic markers after training. This suggests that a MIX program may have higher trainability properties [60] that relies on synergy to compensate for the potential negative effects of some short- and mid- term performance constraints (e.g., fatigue status). That is, higher training variability pushes individuals to explore and discover new synergies, not only muscular [61] but also physiological and psychobiological [49,62], that improve trainability, speed of adaptation, and upper limits. Successful training likely stimulates different processes to improve one's ability to find effective responses under permanently changing internal and environmental conditions [63]. Training variability, in turn, creates adaptations during the training period that are reflected in stronger and longer effects during post-training and detraining periods.

The delay in recovering the initial state after an initial training perturbation, the so-called hysteresis or detraining effect, reflects exercise strain and tolerance [33]. These effects were explored three weeks after in this study. Although the STR program failed to show any significant retention of either aerobic (W_{max}) or anaerobic (W × time) markers, consistent with reports in previous studies [50,64], the MIX training program showed large detraining effects in aerobic performance. A larger hysteresis area indicates greater energy dissipation [65], leading to a greater strain and impact on physiological systems. Thus, although the AER, STR and MIX training programs had similar external loads (same volume), they produced different internal loads [41]. This internal load, represented by the hysteresis area, was larger in the MIX program and characterized by combined inputs. Comparable results are found in high-intensity interval training (i.e., so-called HIIT programs) that increase effectivity by producing higher intensity variations compared with continuous training [66].

Some practical implications relevant to the design of adequate standardized training programs can be extracted from the current results. The inter-individual training response variability and detraining effects of the MIX program point to this type of training has been most effective for developing aerobic and anaerobic markers performance. The negative interferences of molecular pathways involved in endurance and strength training, and the compromise in adaptation resulting from MIX training, seem to be affected by training volume, intensity, type, frequency, and history [43]. While high volume and frequent endurance training may negatively affect adaptations induced by strength training, the moderate intensity and moderate training volume applied in this study seems to promote synergistic effects. It seems plausible that young adults, the elderly, patients, and athletes might benefit from such effects, though further research will be needed.

Study Limitations and Future Directions

Concerning the study's limitations, the sample included only a short number of young males due to the exploratory purpose of the research. Increasing the number of participants could reveal additional significant results, specifically with respect to AER training. However, this limitation does mean that we cannot generalize the present findings to all populations, and that future large-scale studies are needed that include females, other age groups, people with different fitness levels, and people with different health conditions. The lack of specificity of the cycling tests with respect to the STR training program should also be considered when interpreting our results. Finally, the sensitivity of the quantitative variables under study (e.g., VO_{2max} and W_{max}) may have been inadequate to reflect the training effects produced by the AER and STR programs. Some authors propose the use of coordinative variables like cardiorespiratory coordination to increase sensitivity, arguing that coordinative variables may predict and precede changes observed in quantitative variables [4]. In such a way, the hysteresis area could become a novel biomarker to evaluate not only the fitness status [33] but also the effectivity of different training interventions. Future research based on network physiology and connectivity measures is warranted to clarify the complex and synergetic effects of training programs and to improve the sensitivity of current evaluation variables and tools.

Conclusion

A mixed program of aerobic and strength training demonstrated higher improvements in the studied markers of performance, with lower inter-individual response variability, and longer detraining effects compared with aerobic or strength programs.

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