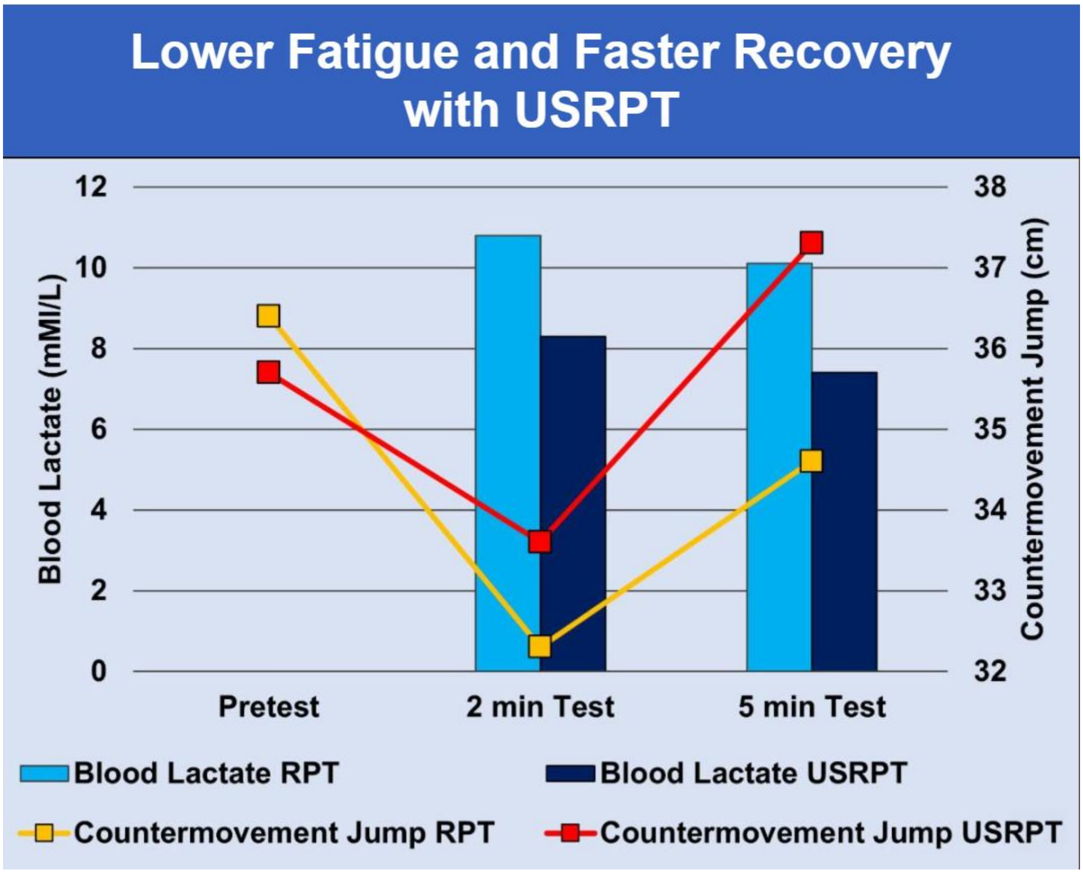
Lower fatigue and faster recovery of ultra-short race-pace swimming training sessions



Greetings to my esteemed readers. My name is Mohammad Deljoo (Coach Mohammad), and I am thrilled to delve into a topic that holds great significance for athletes: Lower fatigue and faster recovery of ultra-short race-pace swimming training sessions. This discussion stems from my ongoing commitment to advancing knowledge in the realm of swimming coaching, particularly in optimizing training methodologies.

This study investigated the impact of two high-intensity swim training protocols. The comparison between Ultra-Short Race-Pace Training (USRPT) and Traditional High-Intensity Training (RPT) revealed notable differences in lactate levels, fatigue responses, and performance outcomes. USRPT demonstrated lower lactate accumulation and reduced fatigue, making it a promising method for achieving race pace with less metabolic stress. The study highlights the potential benefits of incorporating USRPT into swim training regimens, offering swimmers an effective strategy to enhance performance while minimizing fatigue.

Best Regards

Mohammad Deljoo

ABSTRACT:

In order to improve particular race techniques, swimmers use a high-intensity training method called ultra-short race-pace training (USRPT). Its application nevertheless, not much is known about the related weariness. The acute responses of two volume-equated sessions (1000 meters) were examined in a crossover design among 14 national swimmers: i) 20×50 m for USRPT; ii) 10×100 m for RPT. Both regimens were based on individual 200-meter racing paces and maintained a comparable work recovery ratio (1:1). Using mixed-models, swimming times and arm-stroke counts were tracked and evaluated. Two and five minutes after the protocols were followed, blood lactate [La] and countermovement jump-height (CMJ) were measured. The last few RPT swims were 1.5–3% slower than the goal pace, with an arm-stroke increase of about 0.22 for every extra second of swimming. In comparison to RPT (2 min: 10.9±2.3; 5 min: 9.9±2.4 mM/L [p = 0.008]), USRPT showed lower [La] (2 min: 8.2±2.4 [p = 0.021]; 5 min: 6.9±2.8 mM/L [p = 0.008]). After RPT (-11.09%) and USRPT (-5.89%), CMJ dropped at minute 2, but USRPT returned to baseline at minute 5 (4.07%). To sum up, USRPT showed better recovery and less fatigue than conventional high-volume sets.

Keywords: short-term potentiation, endurance training, athletic performance, physical conditioning, and high-intensity interval training (HIIT).

INTRODUCTION:

Training volume for competitive swimming must be high in order to build the physiological factors needed for success. Long-duration workouts that cause lactate buildup and glycogen exhaustion are typically recommended by coaches [La]. High-volume, low-intensity training patterns are frequently followed by elite middle-distance swimmers (200–400 m) (55-70% below [La–] 2 mM/L and 30-45% between [La] 2 and 4 mM/L). The goal of this strategy is to increase aerobic capacity (VO2max) and the capacity to maintain it. To stimulate multiple energetic pathways and aerobic power, training should include activities at race-specific velocities, as the energy for swimming speed is obtained from that particular pace. This covers intensities that can stimulate the glycolytic system above [La] ~4 mM/L and ~75-80% of VO2max.

Maintaining high-intensity exercises throughout high-volume training sessions might be difficult because it significantly depletes ATP and phosphocreatine reserves (PCr), which increases tiredness. The polarized training paradigm is an alternate strategy to improve race-specific velocity training and achieve endurance performance increases. In this model, 75–80% of the training time is spent at low intensities (< 2 mM/L [La]), 20% of the time is spent at high intensities (> 4 mM/L [La-]), and the remaining 20% of the time is spent at minimum or no training (0–5%) in between (2 mM/L ≥ [La] ≤ 4 mM/L). To do this, coaches frequently use Ultra-short race-pace training (USRPT), a high-intensity training (HIT) variant. Short bursts of intensive exercise, such as 20 to 50 swimming intervals over short distances of 15 to 100 meters, are used in USRPT to stress the aerobic and glycolytic systems. Work-recovery ratios can be set at 1:1, 1:2, or 2:1 depending on the competitive race pace of the individual.

Increased VO2max, enhanced ATP synthesis and utilization from the glycolytic system, increased velocity at the [La] threshold, and a reduction in the energy cost of swimming (-20%) are among the anticipated adaptations following USRPT. There isn't much scientific data regarding USRPT protocols in swimming, even though they are commonly used in programs. Research on sprint interval training (SIT) in cycling, for example, showed that shorter bouts of SIT resulted in better cardiorespiratory and power performances with less tiredness than longer HIT sessions equivalent by volume. It is expected that USRPT would produce lower [La] than higher-volume training modalities due to its transient nature.

Although more research is required, this decreased acidity may support oxidative metabolism and sustained race-pace training at the targeted intensity.

The question of whether USRPT can achieve or maintain the intensity needs ([La] > 4 mM/L) required to enhance aerobic capacity remains unanswered because the accumulation of training load at higher intensities is associated with long-term adaptations following high-intensity interval training regimens. Previous studies on a 20 × 25-m USRPT session (100-m race-pace; 35-s rest) showed HRmax ≥ 88%, a rating of perceived effort values ≥ 17, and [La] of 11.4 ± 3.7 mM/L, indicating the feasibility of this HIT modality. Nevertheless, after a set of 40 × 25-m (100-m race-pace; 15-s rest), only [La] ~3 mM/L and 93% HRmax were observed in another investigation, suggesting possible variances in [La] production and elimination. Further experimental validation is required to clarify these points.

Hence, given the considerable variation in [La] responses among athletes, individual assessment of this aspect becomes crucial to gain a deeper understanding of the metabolic responses to this type of training.

It is anticipated that the specific fatigue induced by USRPT would impact various performance variables. Athletes' fatigue is commonly defined as a reduced capacity for maintaining maximal performance, as assessed through various methods. To effectively evaluate fatigue, athletes should be tested using well-established assessments. Considering that USRPT prioritizes race-specific technique instruction and that swimming biomechanics significantly influence performance, analyzing swimming patterns, such as arm-stroke count, could offer an accurate measure of fatigue during race-pace training. Additionally, since muscle power is likely affected by the specific fatigue of USRPT, examining performance in subsequent dry-land exercises could provide insights into how fatigue develops, aiding in the monitoring of muscle power.

Swimming practices involve aspects that necessitate the development of strength and explosive power in dryland conditions, such as the swim start. Unfortunately, these practices are often inadequately controlled or assessed, leading swimmers to perform these exercises under fatigue, thus limiting desired adaptations. In this context, the countermovement jump (CMJ) has proven to be a simple, reliable, and sensitive tool for identifying neuromuscular fatigue after various high-intensity training schemes in different sports. Considering that coaches commonly include jumping exercises in dry-land training due to their strong correlation with swimming start performance, CMJs could be employed to assess readiness for performing strength exercises after swimming exercises of varying intensities.

Therefore, the objective of this study was to compare two volume-equated race-pace sessions—short bouts, exemplified by Ultra-short race-pace training (USRPT), versus long bouts—to evaluate the metabolic (lactate), biomechanical (arm-strokes), and neuromuscular (countermovement jump - CMJ) effects of fatigue during and after each training session. Building on previous evidence in swimming and other sports, it is acknowledged that the rate of [La] depends on the intensity and duration of the swimming effort. Consequently, it is expected that the brief efforts and intermittent activity characteristic of USRPT could contribute to lower [La] levels and reduced fatigue when compared to a longer bouts-HIT-session of equated volume.

Subjects:

Based on a previous study investigating the pre-post effects of two cycling-based Sprint Interval Training (SIT) on countermovement jump (CMJ) height in active men (16x5-s SIT and 4x20-s SIT), sample size calculations for the interaction effect between training modalities were conducted. Using G*Power with F tests and an α error of 0.05, assuming $\eta p^2 = 0.21$ for a repeated measures ANOVA (within factors: protocol - RPT and USRPT, time - 2 min pre-, 2 and 5 min post-), the analysis revealed a minimum of 8 subjects to achieve a statistical power > 80% (estimated correlation = 0.5).

Ultimately, 14 national competitive swimmers were recruited for the study after being informed about the procedures and providing signed consent to participate. The characteristics of the participants were as follows: age - 18.95 ± 1.63 (males) and 19.02 ± 0.78 (females) years old; short course 100-m freestyle time - 56.35 ± 1.44s (males) and 63.01 ± 1.60s (females), corresponding to 509 ± 39 FINA points. Swimmers under the age of 18 also provided signed parental consent forms. The experiment was conducted during the second macrocycle of the season to ensure that swimmers were aerobically fit. Participants abstained from drinking caffeinated beverages and followed their normal diet during the tests. All procedures adhered to the Declaration of Helsinki guidelines for human research, and the study received approval from the local university ethics committee (code: 852).

Design:

A counterbalanced crossover design was employed to assess differences in lactate ([La]), arm-strokes count, and countermovement jump (CMJ) height between two swimming race-pace protocols. The first protocol consisted of 10 × 100-m swimming bouts, referred to as Race-pace training (RPT), while the second protocol comprised 20 × 50-m swimming bouts, denoted as Ultra-short race-pace training (USRPT). In both protocols, swimmers were provided with individualized target times based on specific 200-m times and followed a work-recovery ratio of 1:1.

The interaction effect of [La] and CMJ-height was observed within and between groups at 2 and 5 minutes after each experimental protocol. Additionally, CMJ data were collected immediately prior (2 minutes) to observe pre-post daily changes in neuromuscular function, adhering to established protocols in the literature.

Procedures:

Prior to testing (≥ 48 hours), swimmers underwent a short-course 200-m freestyle test to determine individual target times. This distance was chosen as it ensures that swimmers achieve VO2max and activates the glycolytic system. The RPT target time was calculated as 95% of the 200-m time/2 (males: 65.71 ± 1.38s; females: 71.85 ± 1.95s), while in USRPT, it was calculated as 95% of the 200-m time/4 (males: 32.85 ± 0.65s; females: 35.92 ± 1.10s). To maintain a work-recovery ratio of 1:1, a total bout time of 130 seconds for males and 140 seconds for females was allowed in RPT, and 60 seconds for males and 70 seconds for females in USRPT.

The experimental setting was a 25-m indoor pool with water and air temperatures of 28.3 and 28.9°C, respectively. Before testing, subjects included various countermovement jump (CMJ) attempts during regular training for familiarization. On the test day, subjects completed a standardized 400-m in-water warm-up, followed by two CMJs and 10 minutes of rest. Subsequently, swimmers performed the first CMJs separated by 10 seconds and entered the water to execute one experimental protocol (RPT or USRPT). All efforts were monitored by a certified swimming coach, who provided immediate timing feedback at the end of each effort.

Blood lactate ([La]) samples were collected at 2 and 5 minutes after the tests. A blood lactate analyzer (Lactate Pro2 LT-1730, Arkray, Inc., Kyoto, Japan) was used after collecting ~5 µL of capillary blood from the fingertip, with a measurement range of 0.5 ~ 25.0 mM/L. The analyzer was calibrated according to the manufacturer's instructions using the YSI Preservative Collection Kit (Yellow Springs Inc., Yellow Springs, Ohio, USA).

Arm-stroke counts were diligently monitored during the sets by a researcher to prevent any biases from swimmers. Underwater movements after the push-off from the wall were restricted to a maximum of two kicks. The sum of the values for each lap was averaged over the entire bout, resulting in an arm-stroke average. The countermovement jump (CMJ) height was assessed 2 minutes before the experimental set and 2 and 5 minutes after completing it. Two CMJs were performed per time interval and subsequently averaged for comparisons. An intraclass correlation coefficient was applied between the CMJs attempts (model: two-way mixed; type: absolute agreement), indicating high relative reliability (0.97 [0.92 – 0.98] for 2 min pre-, 0.92 [0.82 – 0.97] for 2 min, and 0.96 [0.93 – 0.98] for 5 min).

The jumping height was calculated using the flight time of the CMJ measured by a contact platform connected to a digital timer (Newtest OY, Oulu, Finland). Participants started from a standing position with a straight trunk, extended legs, and both hands on the hips to minimize lateral and horizontal displacement during jumping. After a countermovement with freely chosen knee flexion, subjects executed the highest possible vertical jump.

Statistical Analysis:

The Shapiro–Wilk test indicated that all variables, except for [La], were normally distributed. Subsequently, differences within protocols of [La] at different time points were analyzed using a two-way non-parametric ANOVA test by Friedman (factors: protocol × time). Paired comparisons were made using the Wilcoxon test between time points and protocols (RPT vs. USRPT). Linear regressions were applied to observe the change trends in swimming time relative to target (%). Data points were pooled and calculated on regression for each gender and training protocol. Swimming times achieved in every effort were then compared with the target times through a paired sample t-test, while the difference between time increments was compared between genders with an independent t-test.

A two-way repeated measures ANOVA, with two repeated-measures factors (protocol and time points), was used to study differences in CMJ-height (2 min pre-, 2 and 5 min post-). Paired sample t-tests were employed to verify differences between time points and protocols (RPT vs. USRPT). Linear mixed-effects models were carried out between arm-strokes count and time achieved in every effort, and repeated-measures correlations were conducted to address the repeated measures within-subjects. Descriptive statistics were expressed as the mean ± standard deviation (SD) and confidence intervals (95% CI). When calculating effect sizes (d), pooled standard deviations (SD) were used as no control group was available (Cohen's $d = [\text{Mean\_a} – \text{Mean\_b}] / \text{SD\_pooled}$). These effect sizes were categorized as small if $0 < |d| < 0.5$, medium if $0.5 < |d| < 0.8$, and large if $|d| > 0.8$. The relative changes (%Δ) were calculated as the percentage difference between conditions ($\%\Delta = [(\text{Mean\_b} – \text{Mean\_a}) / \text{Mean\_ab}] \times 100$). All statistical procedures were performed using SPSS 23.0 (IBM, Chicago, IL, USA), and statistical significance was set at $p < 0.05$.

RESULTS:

A significant protocol, time, and protocol × time interaction (p < 0.001) was identified for [La] when comparing the values collected at 2 to 5 minutes within and between the protocols. The values obtained in RPT (2 min: 10.8 ± 2.7; 5 min: 10.1 ± 2.6 mM/L) were higher than in USRPT (2 min: 8.3 ± 2.7 [p = 0.021]; 5 min: 7.4 ± 2.8 mM/L [p = 0.008]), and both were higher at 2 minutes compared to 5 minutes (p < 0.001). A lower reduction was observed in RPT (Δ = -5.47%; d = 0.22) compared to USRPT (Δ = -11.03%; d = 0.33) (p = 0.015). Combining both protocols, higher [La] was observed in males than in females at 2 minutes (11.3 ± 1.6 vs 7.7 ± 2.8 mM/L; p = 0.008) and 5 minutes (10.6 ± 2.0 vs 7.0 ± 2.8 mM/L; p = 0.025) of recovery.

There was a strong linear trend towards changes in swimming time between Race-Pace Training (RPT) efforts for both males ($R^2 = 0.92$, p < 0.001) and females ($R^2 = 0.94$, p < 0.001) (Figure 2A). Swimming times in RPT were slower than the targeted times for females from the eighth effort onwards (1.55 ± 1.41%, p = 0.025; 2.87 ± 1.86%, p = 0.006; 3.30 ± 1.53%, p = 0.001). In males, the ninth and tenth efforts were slower than the targeted times (1.65 ± 2.24%, p = 0.028; 2.85 ± 2.49%, p = 0.009). The first and second efforts of RPT were faster than the target in males (p = 0.042) and females (p = 0.021). In Ultra-short Race-Pace Training (USRPT), only the first effort of males was faster (p = 0.002). No differences in performance time were observed between males and females in either of the protocols.

The repeated-measures correlation demonstrated that the increased number of arm-strokes was moderately associated with worse time in RPT (Males: r = 0.58, p < 0.001; Females: r = 0.64, p < 0.001) (Figure 2B). Each unit increase in time in 100-m accounted for a 0.24 and 0.20 (p < 0.001) increase in the number of arm-strokes for males and females, respectively. In USRPT, the increased number of arm-strokes was poorly associated in males (r = 0.28, p = 0.001) but not associated in females (r = 0.10, p = 0.241). In males, each unit increase in time in 50m accounted for a 0.30 increase (p < 0.001) in the number of arm-strokes.

A significant time effect (F2,26 = 22.177, p < 0.001) and time × protocol interaction (F2,26 = 6.951, p < 0.004) were identified for countermovement jump (CMJ) height when relative changes from 2 min pre- to 2 and 5 min post-exercise were compared between the protocols [2 min post- vs 2 min pre- (Δ = -11.93%) and; [2 min post- vs 5 min post- (Δ = 6.87%)] for RPT; compared to [2 min post- vs 2 min pre- (Δ = -6.06%)], and; [2 min post- vs 5 min post- (Δ = 10.43%)] for USRPT. The paired samples t-test showed a return to baseline at 5 minutes in USRPT, with no differences with 2 min pre- (p = 0.76), and higher CMJ-height compared to RPT (p = 0.021) (Table 1).

DISCUSSION:

The objective of this study was to compare two volume-equated High-Intensity Training (HIT) sessions, namely Ultra-short Race-Pace Training (USRPT: 20 × 50-m) and long bouts (RPT: 10 × 100-m), to assess the lactate and fatigue responses during and after each training session. The hypothesis was that the brief efforts of USRPT could lead to lower lactate levels and reduced fatigue compared to the longer bouts of RPT. The results indicated that both protocols achieved an intensity range within [La] 8-12 mM/L, but RPT produced higher [La]max compared to USRPT.

Furthermore, deteriorations in the swimming pace, stroke patterns (i.e., arm-stroke count), and muscle power (CMJ-height) were more pronounced and persistent in RPT. Therefore, USRPT appears to be the more suitable method to include High-Intensity Training (HIT) aiming to replicate competitive race pace with less fatigue.

Although USRPT and RPT set the same target intensities, the magnitude of [La]max also depends on the exercise duration because glycolysis reaches near maximal rates after ~40-50 seconds[10, 16], resulting in a greater impact on RPT. This was expected, given that 37-63% of the energy supplied for 100-m races comes from glycolysis[17, 39]. Moreover, the Adenosine Triphosphate (ATP) obtained from Phosphocreatine (PCr) is capable of supplying a substantial proportion of the required energy for only 5-7 seconds, favoring lower [La] accumulation in USRPT[10, 15]. Despite the role of [La] acidosis as the main cause of fatigue being disregarded[3, 10], severe reduction in pH may hinder ATP utilization when [La] values reach ~13-30 mM/L [1, 13]. Some swimmers obtained 12-14 mM/L of [La], confirming that the glycolytic system was highly activated through this protocol. Therefore, it can be suggested that USRPT induced an optimal range of [La] (≥ 4 mM/L < 13 mM/L), supporting its use as an important HIT modality in swimming[11, 16].

Previously, values of [La] ~9-10 mM/L have been reported for maximal 50-m freestyle bouts[17, 39], while values of [La]max ~11-13 mM/L for maximal 100-m freestyle bouts were observed[17, 31, 39]. Therefore, it was reasonable to expect the lower values observed in the current study using the 200-m race-pace (USRPT: 8.3 ± 2.7 mmol/l; RPT: 10.8 ± 2.7). Nevertheless, it was also noticeable that we measured them after a total volume of 1000-m, which is in agreement with the [La] previously reported for HIT[12].

Interestingly, there was a ~11% reduction in [La] in USRPT but only a ~5% reduction in RPT. One possible explanation for this difference might be that, following RPT, some subjects may reach true peak [La] values between minutes 2 and 5, therefore not showing the expected reduction in [La] values (Figure 1). Further studies should examine the [La] kinetics to confirm this possibility.

In any case, active muscles contribute to higher [La] removal during exercise and also during recovery[1, 33], whereas higher mitochondrial and capillary content contributes to obtaining a higher energy fraction from muscular oxidative metabolism[11, 12]. Actually, when the recovery time between efforts declines, there is a reduction in the use of fast-twitch glycolytic fibers and an increase in the reliance on slow-twitch oxidative fibers, thus contributing to greater [La] clearance[12]. The different recovery periods (35 vs. 15 seconds) may explain the [La] differences obtained by Williamson et al[19] and Gullstrand and Lawrence[20] (~11 and ~3 mM/L, respectively), while in this current study, those differences were explained by both the different recovery and bouts duration.

The total swimming time increased in RPT but remained more stable in USRPT (Figure 2A). Thus, a lower volume at race-pace intensity was achieved in RPT. Interestingly, the repeated-measures correlation analysis conducted within-subjects showed that increasing the number of arm-strokes entailed worse times in RPT (Males: $r = 0.58$; $p < 0.001$; Females: $r = 0.64$; $p < 0.001$), whereas this relation was not evidenced in USRPT (Males: $r = 0.28$; $p = 0.001$; Females: $r = 0.10$; $p = 0.18$) (Figure 2B). For a given distance and speed, a higher number of arm-strokes would represent a higher stroke rate and a lower stroke length, and this could be related to a reduced capacity to generate propulsive impulse per stroke[7, 23], resulting in a higher energy cost[8]. Previous studies have stated that the stroke patterns remain stable at slow to moderate speeds and in shorter distances[7, 8]; thus, the deleterious effects of fatigue could be better perceived in extended bouts such as RPT. From these results, it may be suggested that the generated metabolic fatigue may have worsened the propelling efficiency by means of changes in the stroke technique[8].

Some studies have demonstrated that CMJ can be a useful tool for identifying acute fatigue after different high-intensity efforts.

For instance, Jimenez-Reyes et al [26] showed post-exercise CMJ-height significantly lower (16.0 ± 2.5%) than pre-exercise following several repetitions of running sprints up to a loss of 3% in speed, while Benítez-Flores et al[15] showed that CMJ-height was lower (4.19%) after 4 × 20-s cycle sprints when compared to 16 x 5-s cycle sprints. Thus, the deterioration in CMJ-height observed after both protocols at minute 2 was somewhat expected. However, the CMJ capacity was quickly restored at minute 5 of recovery only in USRPT, with a trend (p = 0.07) for a CMJ-height potentiation (Table 1). This is an important finding, as a post-USRPT CMJ-height potentiation would be the result of the balance between fatigue and potentiation mechanisms[22].

In this regard, it is worth mentioning that one study on cycling-based SIT (5 s) showed that some individuals potentiated their CMJ-height after the fatiguing protocol[15]. Hence, if fatigue had a direct force-depressing effect in muscles, this was possibly counteracted by other potentiation factors that increased force to the same extent after some minutes of rest[30]. Muscles respond with varying fatigue and potentiation manifestations depending on the recent contractile history[40]. As these two elements can coexist, the quality of muscle performance following contractile activity depends on the balance between the degree to which the muscle is fatigued and the degree to which the muscle is potentiated[41]. The deviating time course of performance enhancement is an individually regulated response that depends on the training experience and on the nature of the participant's muscle fiber composition; thus, stronger athletes could be more resistant to fatigue following a conditioning activity, responding more favorably than weaker athletes [42]. In any case, it is reasonable to expect that the fatigue effects would be eliminated after a few minutes of rest, and this may have entailed greater potentiation responses in USRPT, but also in RPT. Therefore, future studies should look further for potentiation/fatigue effects during different recovery intervals after the training set leading up to the usual 15-20 minutes of rest given between the warm-up and the race.

This study presented some limitations. First, apart from [La□365], this study did not include 366 other physiological measurements, such as heart rate responses; however, previous 367 studies have already demonstrated that USRPT elicits ~88-93% of HRmax which are 368 compatible with HIT demands[19, 20]. Second, while we equated the volume of the two 369 conditions, it should be considered that the purpose of race-pace training is to achieve a 370 certain total volume without fatigue-induced declines in swimming speed; therefore, in a 371 real setting, the coach would adjust the number of sets based on the current loads and 372 fitness level of swimmers. Third, it would have also been interesting to test swim-specific 373 fatigue more directly by performing a maximum-effort swim (e.g., 50 m or 100 m) pre-374 and post-training protocols. This would have allowed a very clear and valid assessment of 375 of true fatigue-performance reduction. However, such efforts may limit the conditions of 376 states of the activities to be carried out immediately afterward (e.g., dry-land training). 377 Future studies should evaluate the different responses evaluated in the current study, 378 including individualized loads and volumes to verify if this HIT modality effectively 379 results in better chronic training adaptations. 380 381 In conclusion, for a given training volume, USRPT is better than RPT to achieve more 382 volume at a race pace, maintaining the swimming patterns with considerably lower 383 metabolic and neuromuscular fatigue. Therefore, it is reasonable to suggest that 384 increasing the frequency of USRPT training with lower metabolic stress and fatigue 385 would allow athletes to accumulate more HIT volume at race-specific velocity. Similarly, 386 RPT could be an interesting method for long-distance swimmers to create more stress to train [La□387] tolerance. Future studies should test the long-term adaptations obtained 388 through these procedures.

References:

1. Greenwood, J.D., et al., Intensity of exercise recovery, blood lactate disappearance, and subsequent swimming performance. Journal of Sports Sciences, 2008. 26(1): p. 29-34.
2. Nugent, F.J., et al., Effects of low-volume, high-intensity training on performance in competitive swimmers: a systematic review. Journal of Strength and Conditioning Research, 2017. 31(3): p. 837-847.
3. Ferguson, B.S., et al., Lactate metabolism: historical context, prior misinterpretations, and current understanding. European journal of applied physiology, 2018. 118(4): p. 691-728.
4. Meckel, Y., et al., The relationship between short-and long-distance swimming performance and repeated sprint ability. The Journal of Strength & Conditioning Research, 2012. 26(12): p. 3426-3431.
5. Hellard, P., et al., Elite swimmers' training patterns in the 25 weeks prior to their season's best performances: insights into periodization from a 20-year cohort. Frontiers in Physiology, 2019. 10: p. 363.
6. Ribeiro, J., et al., VO_2 kinetics and metabolic contributions during full and upper body extreme swimming intensity. European journal of applied physiology, 2015. 115(5): p. 1117.
7. Santos, K.B.d., et al., Kinematic Parameters After Repeated Swimming Efforts in Higher and Lower Proficiency Swimmers and Para-Swimmers. Research Quarterly for Exercise and Sport, 2020. 91(4): p. 574-582.
8. Zamparo, P., M. Cortesi, and G. Gatta, The energy cost of swimming and its determinants. European Journal of Applied Physiology, 2020. 120(1): p. 41-66.
9. Nugent, F., et al., Ultra-short race-pace training (USRPT) In swimming: current perspectives. Open Access Journal of Sports Medicine, 2019. 10: p. 133.
10. Brooks, G.A., Lactate as a fulcrum of metabolism. Redox biology, 2020. 35: p. 101454.
11. MacInnis, M.J. and M.J. Gibala, Physiological adaptations to interval training and the role of exercise intensity. The Journal of physiology, 2017. 595(9): p. 2915-2930.
12. Laursen, P.B. and D.G. Jenkins, The scientific basis for high-intensity interval training. Sports medicine, 2002. 32(1): p. 53-73.
13. Gorostiaga, E.M., et al., Vertical jump performance and blood ammonia and lactate levels during typical training sessions in elite 400-m runners. The Journal of Strength & Conditioning Research, 2010. 24(4): p. 1138-1149.
14. Hydren, J.R. and B.S. Cohen, Current scientific evidence for a polarized cardiovascular endurance training model. The Journal of Strength & Conditioning Research, 2015. 29(12): p. 3523-3530.
15. Flores, S.B., et al., Shorter sprints elicit greater cardiorespiratory and mechanical responses with less fatigue during time-matched sprint interval training (SIT) sessions. Kinesiology, 2018. 50(2): p. 137-148.
16. Smith, D.J., S.R. Norris, and J.M. Hogg, Performance evaluation of swimmers. Sports medicine, 2002. 32(9): p. 539-554.
17. Zacca, R., et al., Lactate peak in youth swimmers: quantity and time interval for measurement after 50-1500 maximal efforts in front crawl. J Physiol, 2014. 66: p. 90-95.
18. Buchheit, M. and P.B. Laursen, High-intensity interval training, solutions to the programming puzzle. Sports Medicine (Auckland, NZ), 2013. 43(5): p. 313-338.
19. Williamson, D., E. McCarthy, and M. Ditroilo, Acute Physiological Responses to Ultra Short Race-Pace Training in Competitive Swimmers. Journal of Human Kinetics, 2020. 75(1): p. 95-102.

20. Gullstrand, L. and S. Lawrence, Heart rate and blood lactate response to short intermittent work at race pace in highly trained swimmers. Aust J Sci Med Sport, 1987. 19(1): p. 10-14.
21. Taylor, K., et al., Fatigue monitoring in high performance sport: a survey of current trends. J Aust Strength Cond, 2012. 20(1): p. 12-23.
22. Boullosa, D., et al., A new taxonomy for post-activation potentiation in sport. International Journal of Sports Physiology and Performance, 2020: p. 1-14.
23. Cuenca-Fernández, F., J.J. Ruiz-Navarro, and R. Arellano Colomina. Strength-velocity relationship of resisted swimming: A regression analysis. 2020. ISBS-Conference Proceedings Archive. Vol. 38: Iss. 1, Article 99.
24. West, D.J., et al., Strength and power predictors of swimming starts in international sprint swimmers. The Journal of Strength & Conditioning Research, 2011. 25(4): p. 950-955.
25. Gathercole, R., et al., Alternative countermovement-jump analysis to quantify acute neuromuscular fatigue. International journal of sports physiology and performance, 2015. 10(1): p. 84-92.
26. Jiménez-Reyes, P., et al., Jump height loss as an indicator of fatigue during sprint training. Journal of sports sciences, 2019. 37(9): p. 1029-1037.
27. Crowley, E., A.J. Harrison, and M. Lyons, The impact of resistance training on swimming performance: A systematic review. Sports medicine, 2017. 47(11): p. 2285-2307.
28. Calderbank, J.A., P. Comfort, and J.J. McMahon, Association of Jumping Ability and Maximum Strength With Dive Distance in Swimmers. International Journal of Sports Physiology and Performance, 2020. 1(aop): p. 1-8.
29. Faul, F., et al., G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior research methods, 2007. 39(2): p. 175-191.
30. Cuenca-Fernandez, F., et al., Nonlocalized postactivation performance enhancement (PAPE) effects in trained athletes: a pilot study. Applied Physiology Nutrition and Metabolism, 2017. 42(10): p. 1122-1125.
31. Carvalho, D.D., et al., Anaerobic Threshold Biophysical Characterisation of the Four Swimming Techniques. International journal of sports medicine, 2020.
32. Neiva, H.P., et al., Warm-up and performance in competitive swimming. Sports Med, 2014. 44(3): p. 319-30.
33. Casuso, R.A., et al., Effects of in-water passive recovery on sprint swimming performance and heart rate in adolescent swimmers. Journal of sports science & medicine, 2014. 13(4): p. 958.
34. Weir, J.P., Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. The Journal of Strength & Conditioning Research, 2005. 19(1): p. 231-240.
35. Bland, J.M. and D.G. Altman, Statistics notes: Calculating correlation coefficients with repeated observations: Part 1—correlation within subjects. Bmj, 1995. 310(6977): p. 446.
36. Lakens, D., Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. Frontiers in psychology, 2013. 4: p. 863.
37. Cohen, J., Statistical power analysis for the behavioural sciences. Hillsdale, NJ: Laurence Erlbaum Associates. 1988, Inc.
38. Cole, T.J. and D.G. Altman, Statistics Notes: What is a percentage difference? Bmj, 2017. 358.
39. Vescovi, J.D., O. Falenchuk, and G.D. Wells, Blood lactate concentration and clearance in elite swimmers during competition. International journal of sports physiology and performance, 2011. 6(1): p. 106-117.
40. Rassier, D. and B. Macintosh, Coexistence of potentiation and fatigue in skeletal muscle. Brazilian Journal of Medical and Biological Research, 2000. 33(5): p. 499-508.

41. Brandenburg, J.P., The acute effects of prior dynamic resistance exercise using different loads on subsequent upper-body explosive performance in resistance-trained men. Journal of Strength and Conditioning Research, 2005. 19(2): p. 427.
42. Seitz, L.B. and G.G. Haff, Factors modulating post-activation potentiation of jump, sprint, throw, and upper-body ballistic performances: A systematic review with meta-analysis. Sports Medicine, 2016. 46(2): p. 231-240.

TABLE & FIGURE CAPTIONS

Figure 1. Maximal blood Lactate concentration ([La522]max) achieved 2 and 5 minutes after the experimental sets (n = 14). Race-pace training (RPT); Ultra-short race pace training (USRPT).

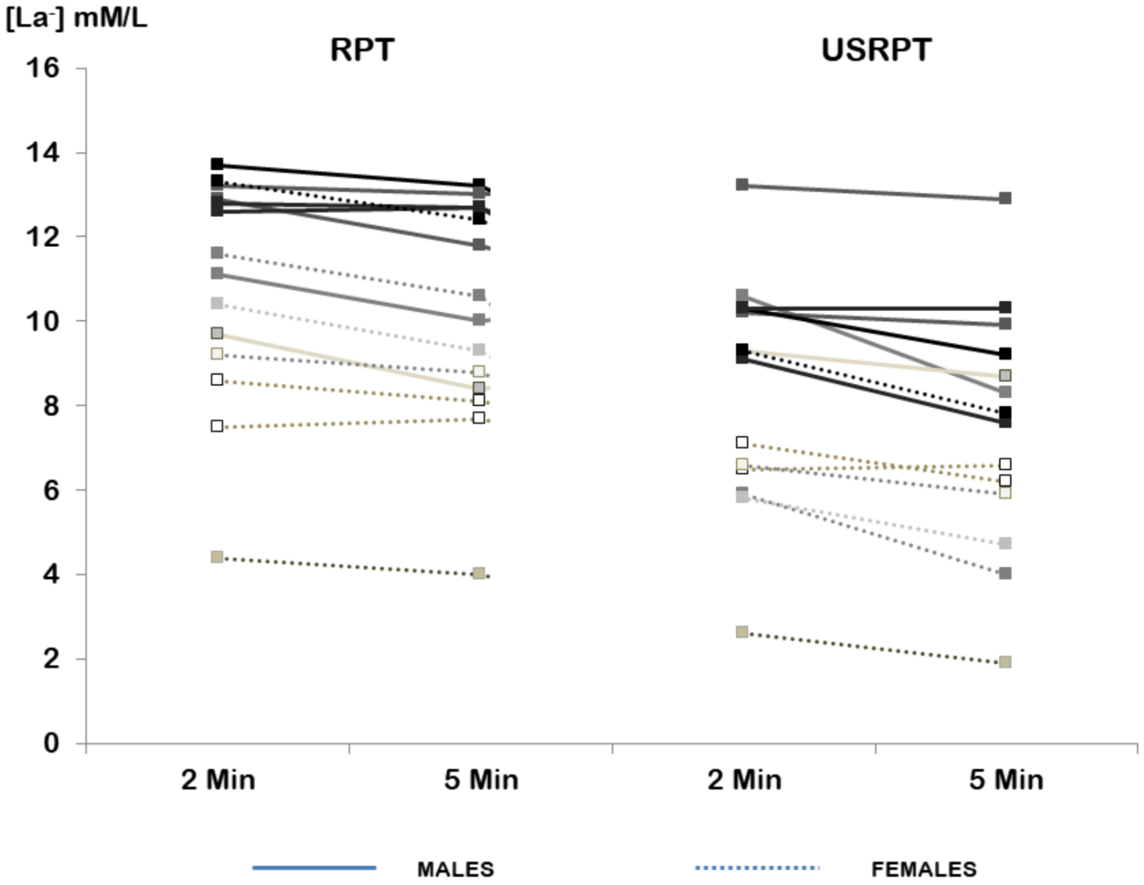


Figure 2. A – Time variation regarding target time (RPT = Race-pace training; USRPT= Ultra-short race-pace training); B – Regression Analysis between arm-stroke count and final time; C – Arm Strokes Average (per lap).

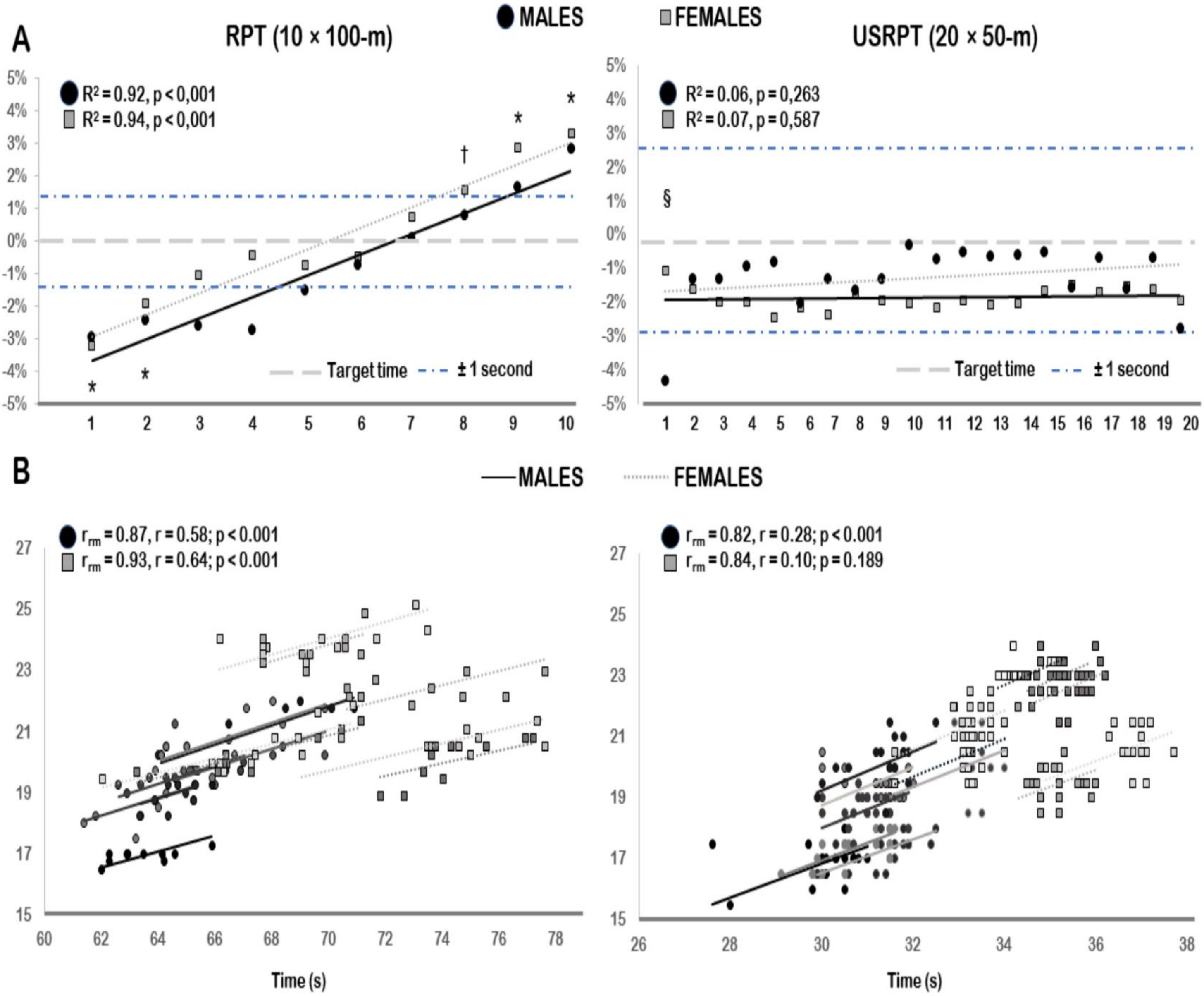


Table 1. Mean ± Standard deviation (SD), confident intervals and effect sizes of countermovement jump height (CMJ), 2 min before (Pre), and 2 and 5 min after the experimental training protocols: Race-pace training (RPT = 10×100-m); Ultra-short race-pace training (USRPT = 20×50-m).

		CMJ – Pre	**Vs**		**CMJ – 2 min**	**Vs**		**CMJ – 5 min**	**Vs (Pre-)**	
		Mean ± SD	**P**	**ES (95% CI)**	**Mean ± SD**	**P**	**ES (95% CI)**	**Mean ± SD**	**P**	**ES (95% CI)**
RPT		36.4 ± 8.4	<0.001	-0.55 (-1.62, 0.51)	32.3 ± 5.8*	<0.001	0.31 (-0.69, 1.42)	34.6 ± 6.3$^{*\#}$	0.026	-0.24 (-1.29, 0.81)
Vs	**p**	0.568			0.239			0.021		
	ES (95% CI)	-0.09 (-0.92, 0.56)			0.17 (-0.40, 1.09)			0.36 (-0.41, 1.13)		
USRPT		35.7 ± 6.4	<0.001	-0.28 (-1.38, 0.72)	33.6 ± 6.2*	<0.001	0.49 (-0.54, 1.59)	37.3 ± 7.5$^{\#\$}$	0.076	0.21 (-0.83, 1.26)