Effects of Repeated Sprint Training in Hypoxia on Physical Performance Among Athletes: A Systematic Review

Efectos del Entrenamiento de Velocidad Repetida en Hipoxia Sobre el Rendimiento Físico Entre Atletas: Una Revisión Sistemática

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SUMMARY: Repeated sprint training in hypoxia (RSH) represents an innovative method in the process of development and improvement of physical performance among athletes. However, there is less scientific data on this topic. The purpose of this systematic review was to investigate the effect of RSH method on motor abilities and performance among athletes, obtain new information, and expand the already known conclusions. The data search was performed of 4 electronic databases for the years 2000-2021 May as follows: Google Scholar, PubMed, Web of Science, and ResearchGate. This search with English language restriction was made by using the following terms, individually/combination: "repeated sprint ability", "hypoxia", "effects", "physical performance", "VO₂max" 844 studies were indentified, and 14 studies were selected (11 male studies, 1 female study, 2 both sexes). Results of this systematic review, a total sample size of 347 athletes (40 females and 307 males, aged 15.3 ± 0.5 - 35 ± 7 years), showed that RSH was an effective training method in improving all monitored variables (i.e. RSAmax, VO₂max). However, it should be noted that major improvements were observed mainly in repeated sprint ability (RSA) tests, and less in aerobic tests (i.e. Wingate and Yo-Yo). In conclusion, based on current scientific studies, RSH is more effective method to improve the physical performance among athletes compared to repeated sprint training in normoxia (RSN). This study suggested that the RSH has a positive effect on the monitored variables in physical performance tests especially related to RSA.

KEY WORDS: Repeated sprint ability; Hypoxia; Effects; Physical performance; VO₂max.

INTRODUCTION

Hypoxia is a physiological state of the body in which there is reduced oxygen saturation in body tissues, caused either by environmental factors (increase in altitude) or by internal factors (Pesta et al., 2011; Dekerle et al., 2012; Billaut et al., 2013; Galvin et al., 2013; Rupp et al., 2013). Training in conditions of hypoxia, most often in a natural environment (such as training at higher altitudes), or in artificial conditions (hyperbaric chambers, portable oxygen filtering devices), can be one of the ways to further improve sports performance (Girard et al., 2013).

Starting from the fact, that short-term sprints associated with short recovery periods, are the most common in all sports (Spencer et al., 2005), where the tendency to achieve the best results during continuous sprints, separated by short periods of active or passive rest (≤ 60 s), is the repeated sprint ability (RSA), which is one of the most important part of physical performance among every athlete (Bishop et al., 2011). Given the high demands placed on athletes with the training method, which emphasizes the development of the ability to repeat high-intensity efforts, can be offered a great benefit to athlete in competitions (Buchheit et al., 2010; Serpiello et al., 2012). Encouraged by such demands, and all the improvements to which high-intensity training methods contribute, athletes have modified and updated their training into repeated short-term sprint training in conditions of hypoxia, which are accompanied by incomplete recovery (repeated sprint training in hypoxia, RSH), and popularity and frequency of RHS method is increasing (Brocherie et al., 2017). During this type of training, RSH, there is a longer engagement and maintenance of the maximum number of
fast muscle fibers, which affects the appearance of better fatigue resistance in tests for the assessment of RSA (Brocherie et al., 2015a). This resistance occurs as a consequence of earlier, long-term mechanical work during training in conditions corresponding to higher altitudes, i.e. up to 3800 m (Brocherie et al., 2015a).

This type of training, RSH, is one of less studied areas in sports science, although the first scientific publication on training in conditions of hypoxia was published more than 50 years ago. Millet et al. (2019), found in their meta-analysis that RSH positively contributed to the improvement of physical performance, especially in RSA, among both individual and team sports athletes. It was also concluded that there was an increasing need for further investigation related to RSH as a training method and its underlying mechanism (Millet et al., 2019). Brocherie et al. (2017), observed in their meta-analysis that there were the positive effects of RSH on the physical performance among athletes, especially on the ability to perform repetitive sprints. Furthermore, it was found the positive effect of this type of training in the field of endurance sports (VO2max was higher) (Brocherie et al., 2017). However, there is still less scientific data on the effect of RSH on individual physical performance among athletes, such as values of the different modalities of RSA, VO2max, as well as on performance in Wingate, and Yo-Yo (YYIR1/YYIR2) tests.

The purpose of this systematic review was to investigate the effect of RSH training method on motor and functional abilities and performance among athletes, obtain new information, and expand the already known conclusions. Also, based on current scientific studies the effect of RSH on RSA, VO2max, performance in Wingate, and Yo-Yo (YYIR1/YYIR2) tests was examined.

MATERIAL AND METHOD

This systematic review was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines (Moher et al., 2009).

Search strategy and study selection. The data search was performed of 4 electronic databases for the years 2000-2021 May as follows: Google Scholar, PubMed, Web of Science, and Research Gate. This search with English language restriction was made by using the following terms and operators AND/OR individually/combination: "repeated sprint ability", "hypoxia", "effects", "physical performance", "VO2max". English was used as a language restriction, the relevance of the titles and abstracts of the identified studies was checked, and only the free full-text versions of original scientific studies in electronically available Journals were accepted for further analysis. The study selection was made by using inclusion and exclusion criteria. Furthermore, the reference lists of relevant study reports were searched to obtain more studies related to this research topic.

Literature search, identification and review of studies was conducted by five authors (MZ, TK, TS, DIA, DB), and the quality of assessment and data extraction was conducted independently by three authors (NA, BB, SMA). To identify relevant studies, all the titles were initially reviewed by the authors during electronic searches to exclude titles that were not relevant. In the initial review 844 potentially acceptable study reports were identified. The study selection process is shown in Figure 1. The full-text versions of the selected studies, which met the inclusion criteria, were included in the procedure and reviewed by all authors, to make the final decision on inclusion in the systematic review of the research. Disagreements between authors were resolved by consensus or arbitration by ZM.

Fig. 1. Selection of studies for systematic review.
Inclusion criteria. For the selection of the studies, which were included in the final analysis, the following criteria for inclusion were defined: (1) original scientific study reports; (2) studies based on longitudinal or parallel or cross-over design; (3) studies written in English; (4) sample of participants - active athletes; (5) duration of experimental treatments of at least 12 days; (6) experimental treatment under conditions of hypoxia and normoxia; (7) a minimum of two groups of participants (1 experimental - 1 control or 2 or more experimental); (8) primary dependent variables - RSA (repeated sprint ability), VO$_{2\text{max}}$ (maximum oxygen consumption), YYIR test, Mean and peak power (produced power during the test); (9) studies where only athletes from dry land sports were tested.

Exclusion criteria. Based on the following criteria, the studies were excluded from the further analysis: (1) studies based on cross-sectional design; (2) written studies in other languages; (3) inadequate sample of participants (non-athletes, obese, over 45 years of age, etc.); (4) studies with a lack of a control group or other experimental group; (5) the experimental treatment lasted less than 12 days; (6) studies where the experimental treatment was not realized in the conditions of hypoxia and normoxia; (7) studies in which the results were not adequately presented or the parameters required for further analysis are missing; (8) studies where the tests were based on animals; (9) studies where water sports athletes were tested; (10) studies related to the case study.

Data extraction. The selected studies in this systematic review are shown in Table I. For each study the parameters are shown: (1) characteristics of the study, including author(s) and year of publication, (2) study design, (3) information on participants such as sample size, sex, age, number of groups and sports groups/type, (4) a description of the experimental procedure that includes training conditions, program duration and training protocol, and (5) variables monitored. Data extraction was carried out by MZ, DB, TS and NA, while TK, BB and ZM checked the extracted data for accuracy and completeness, as well as ZM resolved disagreements if there was no consensus. Finally, selected studies were systematically reviewed by all authors, and the final check was made by TK and MZ.

RESULTS

Study selection. A search of electronic databases identified a total of 844 relevant studies. After removing the duplicates, 483 studies remained. Based on the review of the title and abstract, 242 studies were excluded, 121 studies were rejected due to different training in hypoxia conditions, 7 studies based on an inadequate number of participants and 97 due to inadequate output data. According to clearly defined inclusion criteria, 14 studies met the inclusion criteria included in the systematic review and further analysis. The characteristics of the selected studies are shown in Table I, monitored variables in Table II, and the results are in Tables III and IV.

Study characteristics. All the studies included in this systematic review were published in English between February 2013 and March/April 2020. Most of studies were a parallel single-blind (i.e. Galvin et al., 2013; Gatterer et al., 2014; Goods et al., 2015; Kasai et al., 2015) or double-blind (i.e. Brocherie et al., 2015a, b; Faiss et al., 2015) design. The total sample size was 347 participants, of which 40 were females and 307 were males. 11 studies included only males (Galvin et al., Brocherie et al., 2015a; Faiss et al., 2013; Puype et al., 2013; Gatterer et al.; Brocherie et al., 2015b; Goods et al., 2015; Hamlin et al., 2017; Fornasier-Santos et al., 2018; Beard et al., 2019; Camacho-Cardenosa et al., 2020), one study included female participants (Kasai et al.), and two studies included participants of both sexes (Faiss et al., 2015; Brechbuhl et al., 2018). The age of the participants ranged from 15.3 ± 0.5 to 35 ± 7 years. Four studies investigated the effects of repeated sprint training in hypoxia (RSH) in rugby players (Girard et al., 2013; Hamlin et al.; Fornasier-Santos et al.; Beard et al.), three in football players (Brocherie et al., 2015a; Gatterer et al.; Goods et al., 2015), two in cyclists (Faiss et al., 2015; Kasai et al.), and the rest of studies in hockey (Brocherie et al., 2015b), biathlon (Faiss et al., 2015) tennis (Brechbuhl et al.) and team sports (Camacho-Cardenosa et al.), while one study only mentioned term ‘athletes’ (Puype et al.). The duration of the training program was varied from 12 days (Brechbuhl et al.) to 6 weeks (Puype et al.), and from 5 (Beard et al.) to 18 trainings (Puype et al.). Training conditions ranged for the RSH group from 13% to 14.8% the fraction of inhaled air (FiO$_2$), where they were most often trained at 14.5 % FiO$_2$ and for the repeated sprint training in normoxia (RSN) group from 20.9% to 21% FiO$_2$ (in nine studies 20.9 % FiO$_2$). For more details, see Table I.

The training protocol contained from one (Galvin et al.) to four (Brocherie et al., 2015b; Brechbuhl et al.) series of sprints and from five (Faiss et al., 2013; Gatterer et al.; Brocherie et al., 2015b; Faiss et al., 2015; Hamlin et al.; Brechbuhl et al.) up to ten (Galvin et al.) repetitions. Running time ranged from five seconds (Brocherie et al., 2015a, b) to ten seconds (Faiss et al., 2015; Gatterer et al.; Beard et al.; Camacho-Cardenosa et al.) or a sprint distance of 10 (Brocherie et al., 2015a) to 40 meters (Fornasier-Santos et al.). Also, the training protocol referred to pedaling on a bicycle ergometer, from one (Puype et al.) to four series.
Table I. Characteristics of the selected and analyzed studies.

| Author and year | Study design | Sample of participants | Training conditions | Experimental procedure | Variables |
|-----------------|--------------|------------------------|---------------------|------------------------|-----------|
| Faiss et al. 2013 | A parallel single-blinded design | N = 50 | M = 30; F = 20 | 20 minutes cycling | 4 weeks, 6 workouts, 3x6x30 s (sprint), 5 min at 120W on the bike, at the end 10 min at 120W on the bike | RSAmax, RSAmean (repeated-sprint abilities), total time, number of sprints, distance travelled, maximum power, VO2max |
| Galvin et al. 2013 | A parallel single-blinded design | N = 30 | M = 15; F = 15 | 4x6x30 s (sprint), 30 s | 4 weeks, 4 workouts, 3x6x30 s (sprint), 30 s | RSAI, RSAE (repeated-sprint abilities, total time and number of sprints) |
| Puype et al. 2013 | A parallel single-blinded design | N = 20 | M = 10; F = 10 | 16.9 ± 1.9 (sprint) | 4 weeks, 4 workouts, 3x6x30 s (sprint), 30 s | RSAI, RSAE (repeated-sprint abilities, total time and number of sprints) |
| Gommes et al. 2014 | A parallel single-blinded design | N = 10 | M = 5; F = 5 | 4x6x30 s (sprint), 30 s | 5 weeks, 10 training sessions | RSAmax, RSAmean (repeated-sprint abilities), total time, number of sprints, distance travelled, maximum power, VO2max |
| Brocherie-Millet et al. 2015 | A parallel single-blinded design | N = 32 | M = 16; F = 16 | 4x6x30 s (sprint), 30 s | 5 weeks, 10 training sessions | RSAmax, RSAmean (repeated-sprint abilities), total time, number of sprints, distance travelled, maximum power, VO2max |
| Faiss et al. 2015 | A parallel single-blinded design | N = 17 | M = 8; F = 9 | 4x6x30 s (sprint), 30 s | 5 weeks, 10 training sessions | RSAmax, RSAmean (repeated-sprint abilities), total time, number of sprints, distance travelled, maximum power, VO2max |
| Godin et al. 2015 | A parallel single-blinded design | N = 30 | M = 16; F = 14 | 4x6x30 s (sprint), 30 s | 5 weeks, 10 training sessions | RSAmax, RSAmean (repeated-sprint abilities), total time, number of sprints, distance travelled, maximum power, VO2max |
| Kasai et al. 2015 | A parallel single-blinded design | N = 19 | M = 9; F = 10 | 4x6x30 s (sprint), 30 s | 4 weeks, 4 workouts | RSAmax, RSAmean (repeated-sprint abilities), total time, number of sprints, distance travelled, maximum power, VO2max |
| Hamlin et al. 2015 | A parallel single-blinded design | N = 20 | M = 10; F = 10 | 4x6x30 s (sprint), 30 s | 4 weeks, 4 workouts | RSAmax, RSAmean (repeated-sprint abilities), total time, number of sprints, distance travelled, maximum power, VO2max |
| Beckford et al. 2018 | A parallel single-blinded design | N = 18 | M = 8; F = 10 | 4x6x30 s (sprint), 30 s | 13 days, 5 workouts | RSAmax, RSAmean (repeated-sprint abilities), total time, number of sprints, distance travelled, maximum power, VO2max |
| Fornasiero Santos et al. 2018 | A parallel single-blinded design | N = 21 | M = 13; F = 8 | 2x8x45 s (sprint), 45 s | 4 weeks, 8 workouts | RSAmax, RSAmean (repeated-sprint abilities), total time, number of sprints, distance travelled, maximum power, VO2max |
| Sceurl et al. 2019 | A parallel single-blinded design | N = 19 | M = 15; F = 4 | 2x8x45 s (sprint), 45 s | 4 weeks, 8 workouts | RSAmax, RSAmean (repeated-sprint abilities), total time, number of sprints, distance travelled, maximum power, VO2max |
| Camacho-Cardenosa et al. 2020 | A parallel single-blinded design | N = 24 | M = 14; F = 10 | 2x8x45 s (sprint), 45 s | 4 weeks, 8 workouts | RSAmax, RSAmean (repeated-sprint abilities), total time, number of sprints, distance travelled, maximum power, VO2max |

N number of participants, n subsample, M male, F female, FiO2 oxygen concentration in inhaled volume, RSH repeated-sprint hypoxia, RSN repeated-sprint normoxia, CON control group, HI high-intensity training, RSA repeated-sprint abilities, RSAI repeated -sprint abilities, total time, RSNAnum repeated-sprint abilities, number of sprints, RSAAnum repeated-sprint abilities, distance traveled, RSAmax repeated-sprint abilities, maximum strength, RSAmean repeated-sprint abilities, mean power, VO2max maximum oxygen consumption, Wmax30s Wingate test maximum power for 30s, Wmean30s Wingate test mean power for 30s, YYIR1, YYIR2 interval recovery test, Post transit measurement.
Table II. Monitored variables and representation in studies.

| Variables | RSA | RSAd | RSAmax | Wmax30s | Wmean30s | VO2max | YYIR1 | YYIR2 |
|-----------|-----|------|--------|---------|----------|---------|-------|-------|
| RSAmax    |     |      |        |         |          |         |       |       |
| Wmax30s   |     |      |        |         |          |         |       |       |
| Wmean30s  |     |      |        |         |          |         |       |       |

**Study results.** In a detailed analysis of the procedures and results of RSH studies was found that the studies were mainly conducted with participants who were active athletes (rugby, football, cycling, field hockey, tennis, etc.). In seven studies, one of the aims was to examine the impact of RSH training at the time of pedaling during the test to assess the ability to perform a repeated sprint (RSA). The positive impact of RSH was evident in all participants in six studies (Galvin et al.; Gatterer et al.; Brocherie et al., 2015a, b; Goods et al., 2015; Hamlin et al.; Brechbuhl et al.). However,

Table III. Results of analyzed studies for RSA.

| Author and year | RSA | RSAd | RSAmax | Wmax30s | Wmean30s | VO2max | YYIR1 | YYIR2 |
|-----------------|-----|------|--------|---------|----------|---------|-------|-------|
| Faiss et al., 2013 | RSH 13.06 ± 6.2 *** | RSN 9.06 ± 3.5 | RSH 10.0 ± 15.1 | CON 10.36 ± 6.2 | CON 2 ± 5 |
| Galvin et al., 2013 | RSH 6.7 ± 2.1 % ** | RSN 6.7 ± 3.5 | RSH 6.7 ± 15.1 | CON 6.7 ± 6.5 |
| Gatterer et al., 2013 | RSH 8.7 ± 6.3 % ** | RSN 10.7 ± 3.5 | RSH 8.7 ± 15.1 | CON 10.7 ± 6.5 |
| Brocherie et al., 2015 | RSH 7.3 ± 6.3 % ** | RSN 7.3 ± 3.5 | RSH 7.3 ± 15.1 | CON 7.3 ± 6.5 |
| Brocherie et al., 2015 | RSH 7.3 ± 6.3 % ** | RSN 7.3 ± 3.5 | RSH 7.3 ± 15.1 | CON 7.3 ± 6.5 |
| Faiss et al., 2015 | RSH 17.1 ± 6.8 ** | RSN 17.1 ± 4.3 | RSH 17.1 ± 15.1 | CON 17.1 ± 6.5 |
| Goods et al., 2015 | RSH 11.7 ± 6.8 ** | RSN 11.7 ± 4.3 | RSH 11.7 ± 15.1 | CON 11.7 ± 6.5 |
| Kasai et al., 2015 | RSH 10.4 ± 6.8 ** | RSN 10.4 ± 4.3 | RSH 10.4 ± 15.1 | CON 10.4 ± 6.5 |
| Hamlin et al., 2017 | RSH 10.4 ± 6.8 ** | RSN 10.4 ± 4.3 | RSH 10.4 ± 15.1 | CON 10.4 ± 6.5 |
| Brechbuhl et al., 2018 | RSH 11.4 ± 6.8 ** | RSN 11.4 ± 4.3 | RSH 11.4 ± 15.1 | CON 11.4 ± 6.5 |
| Fornasier-Santos et al., 2018 | RSH 12.4 ± 6.8 ** | RSN 12.4 ± 4.3 | RSH 12.4 ± 15.1 | CON 12.4 ± 6.5 |
| Beard et al., 2019 | RSH 13.4 ± 6.8 ** | RSN 13.4 ± 4.3 | RSH 13.4 ± 15.1 | CON 13.4 ± 6.5 |
| Camacho-Cardenosa et al., 2020 | RSH 14.4 ± 6.8 ** | RSN 14.4 ± 4.3 | RSH 14.4 ± 15.1 | CON 14.4 ± 6.5 |

RSH repeated-sprint hypoxia, RSN repeated-sprint normoxia, CON control group, RSA repeated-sprint abilities, RSAt repeated-sprint abilities, total time, RSAmax repeated-sprint abilities, number of sprints, RSAd repeated-sprint abilities, distance traveled, RSANum repeated-sprint abilities, maximum strength, RSAmean repeated-sprint ability, mean strength, *p < 0.05, **p < 0.01, ***p < 0.001.
In order to assess the impact of RSH training method on the produced maximum or average strength, the authors of two studies included in this systematic review used the Wingate test for 30s as a testing protocol (Faiss et al., 2013; Camacho-Cardenosa et al.) where progress was found in both studies, but without statistical significance (p > 0.05). For more details, see Table IV.

The effect of RSH training method on the improvement of maximum oxygen consumption, for which great heterogeneity was found in the conclusions, was examined in five studies. Progress without statistical significance was found in three studies (Galvin et al.; Brechbuhl et al.; Camacho-Cardenosa et al.). Puype et al., who tested VO2max in their study using the maximum incremental test in hypoxia and normoxia, indicated a statistically significant progress of the experimental group of 6 % to 8 %, while one study did not find any changes after conducting RSH (Kasai et al.). For more details, see Table IV.

The values obtained during the Yo-Yo tests (YYIR1, YYIR2) were tested in five studies and all indicated the improvement of the distance covered during the test, and

### Table IV. Results of analyzed studies for Wingate, VO2max and YYIR.

| Author and year          | Wmax30s       | Wmean30s      | VO2max   | YYIR1       | YYIR2       |
|--------------------------|---------------|---------------|----------|-------------|-------------|
| Faiss et al., 2013       | RSH 718 ± 94 ↑ | RSN 723 ± 86 ↑ | RSH 6.9 ± 9 % ↑ | RSH 33 ± 12 % ↑** | RSN 14 ± 10 % ↑ |
| Galvin et al., 2013      | CON 689 ± 105 ↓ | RSN -0.3 ± 8.8 % ↓ | RSN 6 % -8 % ↑* | CON has no changes |
| Puype et al., 2013       | RSH, RSN 6 % -8 % ↑* | CON has no changes |
| Gatterer et al., 2014    | RSH 1430 ± 458; 1710 ± 183 | RSN 1832 ± 310; 2216 ± RSH 21 % | RSN 22 % ↑*** | RSH 4 % ↑ |
| Brechbuhl et al., 2018   | RSH 14.96 % ↑ | RSH 0.8% ↑ RSN -1.7% ↓ |
| Kasai et al., 2015       | RSH, RSN has no changes |
| Brechbuhl et al., 2018   | RSH Post 3-4-5 |
| Camacho-Cardenosa et al., 2020 | RSH 14.96 % ↑ | RSH 5.89 % ↑ | RSH 15.8 % ↑ |

RSH repeated-sprint hypoxia, RSN repeated-sprint normoxia, CON control group, VO2max maximum oxygen consumption, Wmax30s Wingate test maximum power for 30s, Wmean30s Wingate test mean power value for 30s, YYIR1, YYIR2 interval recovery test, Post transit measurement. ≠ * p < 0.05, ≠ ** p < 0.01, ≠ *** p <0.001.
after the experimental procedure, Galvin et al., indicated a statistically significant progress of the experimental group of 33 ± 12 %. Gatterer et al., found that the participants of the experimental and control groups statistically significantly improved their values before and after the implementation of the program (experimental group; before: 1430 ± 458; after: 1710 ± 183; control group; before: 1832 ± 310; after 2216 ± 395). Statistically significant progress of the experimental and control groups (15 - 33 %) was found in three studies (Brocherie et al., 2015b; Hamlin et al.; Camacho-Cardenosa et al.). For more details, see Table III.

**DISCUSSION**

The purpose of this systematic review was to analyze the selected studies with a current topic related to repeated sprint training in hypoxia (RSH) and its effect on the repeated sprint ability (RSA), VO_{2max}, as well as on performance in Wingate, and Yo-Yo (YYIR1/YYIR2) tests. The results of the selected and systematically reviewed studies showed that RSH was an effective method in improving the ability to perform different modalities of RSA, Wingate, VO_{2max}, and Yo-Yo (YYIR1/YYIR2) tests. However, major improvements were observed mainly inRSA tests, and less in aerobic tests (i.e. Wingate and Yo-Yo). Furthermore, it is important to notice that RSH groups generally achieved better results in physical performance compared to repeated sprint training in normoxia (RSN) and control groups. These results were line with the previous systematic reviews and meta-analyses which suggested that RSH was more effective training method for improving sport-specific performance compared to RSN among athletes, and RSH induced greater gains in RSA (Brocherie et al., 2017; Millet et al.).

RSH has been considered effective in improving RSA, which has been recognized to be very similar to the requirements of team sports in real game conditions (Camacho-Cardenosa et al.). The most common modality of the RSA test was with the measurement of total time during maximum repetitive sprints (RSAi) (Galvin et al.; Gatterer et al.; Brocherie et al., 2015a, b; Goods et al., 2015; Hamlin et al.). Direct comparison of the results of the mean values of the RSAi test was difficult due to the fact that in each of these studies applied different testing protocols, ie variations in the number of series, repetitions, distance, as well as the duration and nature of rest between repetitions. However, observing the results of selected studies and changes recorded in percentages (Brocherie et al., 2015a, b; Goods et al., 2015; Hamlin et al.), it could be suggested that the progress of RSH groups was significantly higher compared to RSN (1.0 - 3.6% vs. - 1.7 - 1.9 %, respectively). Physiological mechanisms such as improved phosphocreatine resynthesis rate and increased mitochondrial activity that occur in the body's adaptation to high-intensity training, such as repeated sprint training in hypoxia, may be responsible for achieving better RSH group results (Bishop & Girard, 2013). Also, it is considered that better results in RSH are a consequence of muscle adaptation at the molecular level in the form of higher oxidative capacity and glycolytic muscle potential, as well as more efficient use of fast muscle fibers (Faiss et al., 2013). In other studies, there were observed shifts in both groups of participants, but no significant differences between them were observed (Galvin et al.; Brocherie et al., 2015a; Goods et al., 2015), while there were no significant differences between pre- and post-treatment testing in either group (Gatterer et al.; Brechbuhl et al.).

The second modality of the RSA test in terms of prevalence is performed on a bicycle ergometer, which gives the values of maximum output power (RSAmax) and mean power values (RSAmean). The results of the RSA test on a bicycle ergometer in most studies (Faiss et al., 2015; Goods et al., 2015; Kasai et al.) showed superior percentage values of RSAmax in RSH compared to RSN (4.7 - 29 % vs. 1.5 - 26 %, respectively), while in the study Beard et al. significant progress was observed only in the RSH group (6.2 %). Maximum strength production during repeated sprints is associated with the ability to recruit more fast-twitch muscle fibers at very high pedaling frequencies, and fast-twitch muscle fibers are known to be crucial in strength production when increasing intensity (Gollnick et al., 1974). Consequently, the observed increase in maximum power could be probably attributed to improved muscle recruitment coordination in terms of recruiting more fast-fiber motor units as well as improved intermuscular coordination (Billaut et al., 2005).

In contrast to the previous findings, the RSN group made greater progress compared to RSH (7 - 8.6 vs. 4.7 - 6 %, respectively) in two studies (Faiss et al., 2013; Goods et al., 2015). This might be a consequence of the reduced achieved training intensity in hypoxia conditions compared to normoxia conditions (Goods et al., 2014). The RSA mean parameters related to the mean power values expressed in the test showed a larger shift of the RSN group compared to RSH (Faiss et al., 2013; 2015; Goods et al., 2015). In contrast, Kasai et al., found that the achieved RSA mean results favored RSH compared to RSN (9.7 vs. 6 %, respectively), while Beard et al. observed a shift only in RSH (6.4 %).

The results achieved in the RSA test, which is realized in relation to the number of completed sections - sprints to exhaustion (RSAnum), indicated that significant improvements in this test were visible only in RSH groups.
In summary, based on the presented results of previous studies and known the underlying mechanisms that occur in hypoxic conditions, it could be concluded that RSH is an effective training method in improving physical performance among individual and team sport athletes. However, it should be noted that greater improvements were observed mainly in RSA tests compared to RSN, and less improvement was observed in aerobic YYIR tests. These results are line with the previous systematic reviews and meta-analyses (Brocherie et al., 2017; Millet et al.).

It is important to emphasize that the observed findings are more methodological in nature, because it is still unclear which methods to choose in terms of duration of stay in hypoxic conditions, exercise modalities (treadmill, pedaling, sprint), exercise volume and intensity, and especially recovery between sets and repetitions. Brocherie et al. (2017), suggested in their meta-analysis that the use of active rest in hypoxic conditions might be an inappropriate method because it slows down muscle re-oxygenation due to lower oxygen replacement in myoglobin and hemoglobin and reduced phosphocreatine resynthesis rate, which can lead to premature fatigue (Dupont et al., 2003; Faiss et al., 2013). Furthermore, it is good to notice that a large number of modalities of RSA tests might be leaded to the appearance of heterogeneity of results, which significantly complicates comparisons between the results. So, RSA tests should be unified, especially in terms of number of repetitions, duration or distance, as well as the duration and nature of rest for the reasons mentioned above. Also, given the specificity of training in hypoxic conditions and its effects, it would be desirable for future studies to monitor changes in the period after experimental treatments, in order to obtain information on how sustainable the effects are.

Finally, there were several strengths of this systematic review. Firstly, this systematic review was conducted in accordance with the PRISMA guidelines. Secondly, the study selection process was independently made by more than one researcher and exactly defined inclusion/exclusion criteria (minimized selection bias and increased internal validity).
Thirdly, the comprehensively reported results (both text and tables) of this study were based on a large study population, both genders, different sport groups, and different ages, which was leading to more comprehensive review of the research topic. However, there were also some limitations, such as study designs of the selected studies varied, and there was used different training and test protocols, which might have impacted the physical performance or physiological adaptation. There could be also used a specific quality assessment tool (i.e. CONSORT checklist, Crowe Critical Appraisal Tool (CCAT) in this review to reduce the heterogeneity of the studies and further increase the generalizability of the results.

In the future it would be interesting to examine with randomized clinical trial study design the effects of RSH on physical performance and health both among individual and team sports athletes on-field in sport-specific settings and patients in the clinical settings. Additionally, the recommendation for further research, related to this research topic, would be to conduct a systematic review and meta-analysis to examine a larger number of high-quality of original studies with randomized clinical trial study design which would follow one type of training protocol, training conditions related to the fraction of inhaled air (FI02), as well as performing sprints during training both on-field in sport-specific settings (i.e. among football players) or sprints on a bicycle ergometer in the laboratory environment (i.e. among cyclists).

CONCLUSIONS

In conclusion, based on current scientific studies, RSH is a promising and more effective method to improve the physical performance among individual and team sport athletes compared to repeated sprint training in normoxia (RSN). This systematic review study suggested that the RSH has a positive effect on the monitored variables in physical performance tests especially related to RSA.

ZELENOVIC, M.; KONTO, T.; STOJANOVIC, T.; ALEXE, D. I.; BOZIC, D.; AKSOVIC, N.; BJELICA, B.; MILANOVIC, Z. & ADRIAN, S. M. Effects of repeated sprint training in hypoxia on physical performance among athletes: A systematic review. Int. J. Morphol., 39(6):1625-1634, 2021.

RESUMEN: El entrenamiento de velocidad repetida en hipoxia (RSH) representa un método innovador en el proceso de desarrollo y mejora del rendimiento físico entre los deportistas. Sin embargo, existen pocos datos científicos sobre este tema. El propósito de esta revisión sistemática fue investigar el efecto del método RSH sobre las habilidades motoras y el rendimiento de los atletas, obtener nueva información y ampliar las conclusiones ya conocidas. La búsqueda de datos se realizó en 4 bases de datos electrónicas: Google Scholar, PubMed, Web of Science e Research Gate para los años 2000- a mayo de 2021. Esta búsqueda se realizó en artículos en idioma inglés mediante el uso de los siguientes términos, individualmente / combinación: “capacidad de sprint repetido”, “hipoxia”, “efectos”, “rendimiento físico” y “VO2max”. Se identificaron 844 estudios y se seleccionaron 14 de ellos (11 estudios realizados en hombres, un estudio realizado en mujeres y dos estudios realizados en ambos sexos). Los resultados mostraron, un tamaño muestral total de 347 atletas (40 mujeres y 307 hombres, de 15,3 ± 0,5 - 35 ± 7 años). Se observó que la RSH fue un método de entrenamiento eficaz para mejorar todas las variables monitorizadas (es decir, RSAmax y VO2max). Sin embargo, se debe tener en consideración que se observaron mejoras importantes, principalmente, en las pruebas de capacidad de sprint repetido (RSA), y menos en las pruebas aeróbicas (es decir, Wingate y Yo-Yo). En conclusión, según los estudios científicos actuales, la RSH es un método más eficaz para mejorar el rendimiento físico entre los atletas en comparación con el entrenamiento de velocidad repetida en normoxia (RSN). Este estudio sugirió que la RSH tiene un efecto positivo sobre las variables monitorizadas en las pruebas de rendimiento físico especialmente relacionadas con RSA.

PALABRAS CLAVE: Capacidad de sprint repetido; Hipoxia; Efectos; Desempeño físico; VO2max.

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