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Effects of the 'Live Low-Train High' Method on Variables of Endurance Capacity. A Systematic Review

Effekte der 'Live Low-Train High'-Methode auf die Ausdauerleistungsfähigkeit. Ein systematisches Review

REVIEW

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Summary

- **Background and Objectives:** A variety of training methods has developed within hypoxic training. The continuous 'live low-train high' method offers simple usability, but effects on endurance capacity are still almost empirically unproven. To clarify whether the continuous 'live low-train high' method has positive effects on the body, it seems worthwhile to collect exploratively the most frequently studied variables and analyze them for similarities.
- **Methods:** A systematic review was conducted to examine the literature on the continuous 'live low-train high' method for the most frequently-tested variables of endurance capacity. Studies which examined continuous endurance training in normobaric hypoxia from the earliest records up to June 2019 were included.
- **Results:** Twelve studies met the criteria and were analyzed. Oxygen uptake at the second ventilatory threshold tested in normoxia exhibits significant changes in six studies through hypoxic training, whereas the changes due to normoxic training are mostly non-significant. The remaining ventilatory, hematological and performance-related variables show only partially significant changes and cannot demonstrate differences between hypoxic and normoxic training.
- **Discussion:** The consideration of the variables revealed similarities in the oxygen uptake at the second ventilatory threshold, but a clear detection of differences between hypoxic continuous 'live low-train high' and normoxic training was not possible. This review offers an overview of already-examined variables and recommends additional consideration of submaximal variables of endurance capacity in study designs.

Zusammenfassung

- **Problemstellung:** In vergangenen Jahren haben sich unterschiedlichste Trainingsmethoden innerhalb des Hypoxietrainings entwickelt. Die kontinuierliche „live low-train high"-Methode bietet eine einfache Anwendbarkeit, doch Effekte auf die Ausdauerleistungsfähigkeit sind nahezu unbelegt. Zur Klärung, ob die kontinuierliche „live low-train high"-Methode positive Effekte auf den Körper besitzt, erscheint es sinnvoll, explorativ die am häufigsten untersuchten Variablen aufzulisten und auf Gemeinsamkeiten zu überprüfen.
- **Methoden:** Ziel dieser systematischen Übersichtsarbeit ist es, die aktuelle Literatur zur kontinuierlichen „live low-train high"-Methode explorativ auf die am häufigsten getesteten Variablen der Ausdauerleistungsfähigkeit zu untersuchen, um zukünftigen Forschungsarbeiten einen Überblick über bereits untersuchte Variablen zu ermöglichen. Eingeschlossen wurden Studien seit Beginn der Dokumentation bis Juni 2019, die kontinuierliches Ausdauertraining in normobarer Hypoxie als Intervention durchführten.
- **Ergebnisse:** Zwölf Studien erfüllten die Einschlusskriterien und wurden zu Analyse herangezogen. Die Sauerstoffaufnahme an der zweiten ventilatorischen Schwelle zeigt in sechs Studien durch hypoxisches Training eine signifikante Steigerung in Normoxie, während die Veränderungen durch normoxisches Training größtenteils nicht signifikant sind. Die verbleibenden ventilatorischen, hämatologischen und leistungsbezogenen Variablen zeigen nur teilweise signifikante Veränderungen und ermöglichen keine Unterscheidung zwischen hypoxischem und normoxischem Training.
- **Diskussion:** Die Betrachtung der Variablen konnte Regelmäßigkeiten der Sauerstoffaufnahme an der zweiten ventilatorischen Schwelle aufweisen, aber eine klare Unterscheidung zwischen der kontinuierlichen „live low-train-high"-Methode und normoxischem Training war nicht möglich. Dieses Review bietet zukünftigen Studien eine Übersicht über bereits untersuchte Variablen und empfiehlt eine zusätzliche Betrachtung von submaximalen Variablen der Ausdauerleistungsfähigkeit im Studiendesign.

KEY WORDS:
Altitude, Hypoxia, Hypoxic Training, Continuous , Cardiopulmonary

SCHLÜSSELWÖRTER:
Höhentraining, Hypoxietraining, Hypoxie, kontinuierlich, kardiopulmonal

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Introduction

Since the Olympic Games 1968 in Mexico City, altitude training has gained increasing attention in sports science and is now widely used for improving athletes' performance (28). The aim of hypoxic training (HT) is the amelioration of performance as well as pre-acclimatization before altitude competitions (21). Different models have evolved within hypoxic training. The 'live high-train high' (LHTH) model represents the origin of altitude training where athletes live and train in hypoxic conditions (17). To avoid decreased training intensity due to reduced oxygen uptake in hypoxia, the 'live high-train low' (LHTL) model was developed (17). Athletes live in hypoxic ›

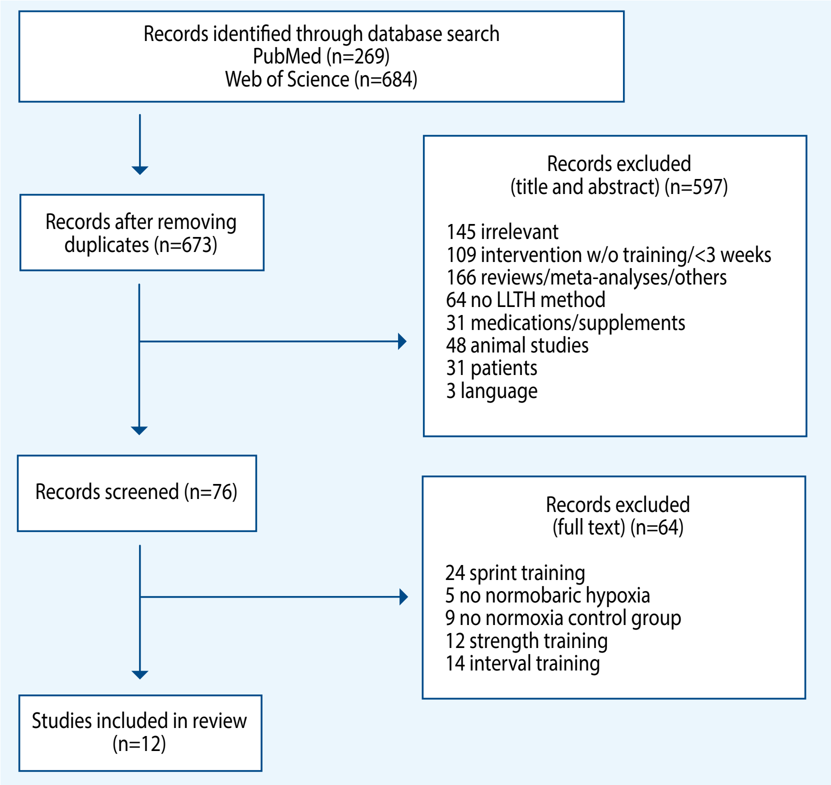

Figure 1

PRISMA flow diagram of research process.

environments whereas training takes place in normoxic conditions. The effectiveness of training stimuli with longer periods of hypoxia (>12h per day, for multiple weeks) has been confirmed by several studies (21), but there is still disagreement within literature with regard to improving sports performance, especially for shorter exposure durations (17).

The 'live low-train high' model (LLTH) is characterized by living in lowlands and training in hypoxia. Within the LLTH model there are further subdivisions into different methods: continuous training, interval training, repeated sprint training, resistance training and passive exposure at rest (18, 20). In all these methods, the lack of oxygen is assumed to lead to adaptive processes for example in muscle tissue (13, 17). General LLTH is relatively easy to implement and provides an appeal to the commercial market (17). While some authors support the viewpoint of the inefficiency of general LLTH (2, 13, 15, 16, 18), other authors attribute positive effects to this model (5, 21, 22). Due to these inconsistent studies, it seems valuable to intensify the examination of this model. Whereas most recent studies inspecting LLTH methods have focussed on interval training and repeated sprint training, it could be beneficial to analyze the continuous LLTH method (cLLTH), which could provide advantages especially for endurance athletes. As soon as the adaptations of the body to cLLTH have been fully clarified, this method could help endurance athletes due to the advantage of a simple usability. Therefore, this review concentrates on cLLTH methods exclusively. The most recent review examining cLLTH by McLean et al. (2014) is based solely on the results of the performance tests ignoring changes in other cardiopulmonary or hematological variables. However, to clarify the effectiveness of the cLLTH model, it seems desirable to consider the entire examined variables to identify possible effects on specific body systems.

Vogt & Hoppeler (2010) also argue that "the global functional markers such as $\dot{V}O_2max$ and power output are too coarse to detect more subtle changes that might still be functionally relevant, at least to high-level athletes" (29).

The aim of this systematic review is to investigate the current literature of the cLLTH method and to explore the most frequently examined cardiopulmonary and hematological variables of endurance capacity tested in normoxia. Subsequently, possible similarities of selected variables should be clarified between studies. It is hypothesized that an examination of a larger number of selected variables than just $\dot{V}O_2max$ or power output may represent differences better between the cLLTH method and normoxic training (NT).

Material and Methods

Search Pattern

A systematic search was performed to collect all relevant studies from the earliest records up to June 2019. For this purpose, the databases PubMed and Web of Science were used. The search was carried out in English and with combinations of the following search terms in 'all fields': (trained OR healthy OR athletes) AND (intermittent OR normobaric) AND (hypoxia OR hypoxic OR altitude) AND (endurance OR performance). The articles found were first selected by title and abstract, afterwards the full text was analyzed for the inclusion criteria.

Inclusion Criteria

To study the effects of the cLLTH model on cardiopulmonary and hematological variables of endurance capacity, the present review focuses on interventional studies which involve only continuous endurance training in hypoxia and living in normoxic conditions. To ensure a homogeneous analysis of selected variables, the following inclusion criteria were determined: 1) Subjects completed endurance training in normobaric hypoxia; 2) The intervention period lasted for a minimum of three weeks; 3) Studies included a control group that trained in normoxic conditions; 4) Studies examined variables for endurance performance. Studies were excluded which examined patients or prescribed medication or supplements. Also, studies with hypobaric hypoxia were excluded because there is still controversy whether hypobaric hypoxia causes different adaptations compared to normobaric hypoxia (1). In addition, studies were excluded which used sprint or strength exercises in hypoxia. Figure 1 depicts the process from database research to the inclusion of studies.

Data Analysis

Due to the heterogeneity of the studies regarding e.g. sample size and duration of intervention, a systematic review was performed without meta-analysis. Only variables that have been examined in at least three studies are listed, as consistent results from different studies may be

Table 1

Overview of the included studies. (H)=tested in hypoxia, HT=hypoxic training, HR=heart rate, HRR_{max}=maximum heart rate reserve, LT2=second lactate threshold, (N)=tested in normoxia, NT=normoxic training, N/A=information not available, PPO=peak power output, VO_2peak=peak oxygen consumption, VT2=-second ventilatory threshold, v_{VT2}=velocity at second ventilatory threshold, WR_{max}=maximum wattage, WR_{LT}=wattage at lactate threshold.

AUTHOR (YEAR)	SUBJECTS HT/NT	ALTITUDE	INTERVENTION	TRAINING PER WEEK	TRAINING INTENSITY	BLINDING
Chobanyan-Jürgens et al. (2019)	untrained 14/15	2750 m	8 weeks (cycling)	3 x 30-40 min	HT: 60-70% VO_2peak (N/A) NT: 60-70% VO_2peak (N/A)	single
Czuba et al. (2018)	cyclists 10/10	2100 m	4 weeks (cycling)	3 x 60-70 min	HT: 60-100% WR_{LT} (H) NT: 60-100% WR_{LT} (N)	N/A
Czuba et al. (2011)	cyclists 10/10	2500-2600 m	3 weeks (cycling)	3 x 60-70 min	HT: 55-95% WR_{LT} (N) NT: 55-100% WR_{LT} (N)	single
Debevec et al. (2010)	untrained 9/9	4500 m	4 weeks (cycling)	5 x 60 min	HT: 50% PPO (H) NT: 50% PPO (N)	none
Dufour et al. (2006)	runners 9/9	3000 m	6 weeks (running)	2 x 24-40 min	HT: VT2 (H) NT: VT2 (N)	N/A
Haufe et al. (2008)	untrained 10/10	2740 m	4 weeks (running)	3 x 60 min	HT: HR at 3 mmol lactate (H) NT: HR at 3 mmol lactate (N)	single
Holliss et al. (2014)	runners 5/7	2150 m	8 weeks (running)	2 x 40 min	HT: HR at LT2 (H) NT: HR at LT2 (N)	single
Messonnier et al. (2004)	untrained 5/8	3800 m	4 weeks (cycling)	6 x 120 min	HT: 60-80% WR_{max} (H) NT: 60-80% WR_{max} (N)	N/A
Ponsot et al. (2006)	athletes 8/7	3000 m	6 weeks (running)	2 x 12-20 min	HT: v_{VT2} (H) NT: v_{VT2} (N)	N/A
Vogt et al. (2001)	untrained 15/15	3850 m	6 weeks (cycling)	5 x 30 min	HT: at 2-3 or 4-6 mmol lactate (H) NT: at 2-3 or 4-6 mmol lactate (N)	N/A
Wang et al. (2010)	untrained 12/12	2733 m	4 weeks (cycling)	5 x 30 min	HT: 50% HRR_{max} (N) NT: 50% WR_{max} (N)	N/A
Wiesner et al. (2010)	untrained 24/21	2740 m	4 weeks (running)	3 x 60 min	HT: 65% VO_2peak (H) NT: 65% VO_2peak (N)	single

considered more valid. For example, the absolute oxygen uptake is not included in the results because it was tested in two studies only.

Results

The systematic search identified 269 articles in PubMed and 684 articles in Web of Science. After removing the duplicates 673 articles were left for further examination. After considering the inclusion and exclusion criteria, 12 studies remained for analysis. A total of 259 participants (HT: n=126; NT: n=133) were examined, who completed two to six training sessions per week with altitude levels ranging from 2100 m to 4500 m (hypoxia group) for a period of three to eight weeks. The hypoxic exposure lasted between 12 and 120 minutes per training session. To guarantee the same relative exercise intensity, all studies except one adjusted the training intensities between the hypoxia and control groups to the respective training environment. Considering the blinding of the studies, five were single-blinded, one was unblinded and six did not indicate blinding (Table 1).

Subsequently, the results will be focused on significant results only. Table 2 shows the results of cardiopulmonary variables, including relative maximum oxygen uptake ($\dot{V}O_2peak$), relative oxygen uptake at the second ventilatory threshold ($\dot{V}O_{2VT2}$), maximum ventilation ($\dot{V}E_{max}$), maximum heart rate (HR_{max}) and maximum respiratory exchange ratio (RER_{max}). $\dot{V}O_2peak$ was investigated in all studies with increases in six studies for HT groups and four studies in NT groups. $\dot{V}O_{2VT2}$ was reviewed in six studies. After HT six studies found rises, whereas after NT one study showed an expand in submaximal oxygen uptake. $\dot{V}E_{max}$ augmented in three out of five studies due to HT. For NT one study showed an increase in $\dot{V}E_{max}$. HR_{max} has been studied in seven protocols. Within HT groups, there were two reductions in HR_{max}. In the NT groups, no significant results could be found. RER_{max} was studied in four investigations. Despite one increase in one of the HT groups, no other results could be found.

Hematological variables are shown in Table 3. Hemoglobin concentration (Hb), hematocrit (Hct), erythrocyte count (Ery) and maximum lactate (Lac_{max}) met the inclusion criteria. Hb, Hct and Ery were tested in four studies but showed no changes neither with HT nor with NT. Lac_{max} was investigated in seven protocols. Despite one increase after HT, no other study detected differences in pre-post-comparisons regardless of group allocation.

Performance variables are shown in Table 4. Endurance capacity was measured by time to exhaustion (TTE), maximum wattage (WR_{max}) and wattage at $\dot{V}T2$ (WR_{VT2}). ›

Table 2

Results of cardiopulmonary variables for hypoxic and normoxic training groups. HR_{max}=maximum heart rate, HT=hypoxic training, NT=normoxic training, N/A=information not available, rel. VO_2peak=relative peak oxygen consumption, rel. VO_{2VT2}=relative oxygen consumption at second ventilatory threshold, RER_{max}=maximum respiratory exchange ratio, VE_{max}=maximum ventilation, ↑=increase, ↓=decrease, ↔=no change, *=significant changes in pre-post comparison (p<0.05).

		Chobanyan-Jürgens et al. 2019	Czuba et al. 2018	Czuba et al. 2011	Debevec et al. 2010	Dufour et al. 2006	Haufe et al. 2008	Holliss et al. 2014	Messonnier et al. 2004	Ponsot et al. 2006	Vogt et al. 2001	Wang et al. 2010	Wiesner et al. 2010
rel. VO_2peak	HT	↑	↑*	↑*	↑	↑*	↑	↓	↑	↑*	↑*	↑*	↑
	NT	↑*	↑	↓	↑*	↑	↔	↑	↑	↑	↑*	↑*	↑
rel. VO_{2VT2}	HT	N/A	↑*	↑*	N/A	↑*	↑*	N/A	N/A	↑*	N/A	↑*	N/A
	NT	N/A	↑	↑	N/A	↑	↔	N/A	N/A	↑	N/A	↑*	N/A
VE_{max}	HT	N/A	↑*	↑*	↑	↑	N/A	N/A	N/A	N/A	N/A	↑*	N/A
	NT	N/A	↓	↓	↑	↓	N/A	N/A	N/A	N/A	N/A	↑*	N/A
HR_{max}	HT	N/A	↓*	↓	↓*	↓	↓	↓	N/A	N/A	N/A	↑	N/A
	NT	N/A	↓	↓	↓	↑	↓	↑	N/A	N/A	N/A	↑	N/A
RER_{max}	HT	↓	↑*	↔	N/A	↔	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	NT	↓	↔	↑	N/A	↔	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 3

Results of hematological variables for hypoxic and normoxic training groups. Ery=erythrocyte count, Hb=hemoglobin concentration, Hct=hematocrit, HT=hypoxic training, Lac_{max}=maximum lactate, NT=normoxic training, N/A=information not available, ↑=increase, ↓=decrease, ↔=no change, *=significant changes in pre-post comparison (p<0.05).

		Chobanyan-Jürgens et al. 2019	Czuba et al. 2018	Czuba et al. 2011	Debevec et al. 2010	Dufour et al. 2006	Haufe et al. 2008	Holliss et al. 2014	Messonnier et al. 2004	Ponsot et al. 2006	Vogt et al. 2001	Wang et al. 2010	Wiesner et al. 2010
Hb	HT	N/A	↓	↑	↔	N/A	N/A	N/A	N/A	N/A	N/A	↑	N/A
	NT	N/A	↑	↔	↓	N/A	N/A	N/A	N/A	N/A	N/A	↓	N/A
Hct	HT	N/A	↑	↑	↔	N/A	N/A	N/A	N/A	N/A	N/A	↑	N/A
	NT	N/A	↑	↑	↓	N/A	N/A	N/A	N/A	N/A	N/A	↓	N/A
Ery	HT	N/A	↑	↑	↑	N/A	N/A	N/A	N/A	N/A	N/A	↑	N/A
	NT	N/A	↑	↑	↓	N/A	N/A	N/A	N/A	N/A	N/A	↓	N/A
Lac_{max}	HT	↑	↑*	N/A	N/A	↓	↔	↓	↑	N/A	N/A	N/A	↓
	NT	↔	↑	N/A	N/A	↑	↓	↓	↑	N/A	N/A	N/A	↓

Seven studies considered TEE, which augmented in two studies after both HT and NT. For WR_{max} five out of seven studies found increases with HT, while for NT three studies showed a growth. WR_{VT2} has been measured in three out of twelve studies. While all three studies found increases for HT, one study showed a rise after NT.

Discussion

The aim of this review was to explore the variables which were investigated the most with interventions based on the cLLTH method and to identify possible similarities of the variables.

The results of $\dot{V}O_2$peak show increasing changes for both groups. A rise in $\dot{V}O_2$peak suggests a general improvement in maximal aerobic capacity and, accordingly, effective training interventions. Only Haufe et al. (2008), Holliss et al. (2014), Messonnier et al. (2004) and Wiesner et al. (2010) could not find any significant changes in $\dot{V}O_2$peak. The lack of improvements in NT groups could challenge the elaboration of the intervention, but there were no obvious differences between these and the other studies regarding the training intervention. Six studies with improvements for HT in comparison to four studies for NT support the current general opinion that cLLTH brings no additional advantage for athletes.

$\dot{V}O_{2VT2}$ is the only variable showing increases for HT groups in all studies which investigated this variable. In NT groups only one study found an increase. A rise of $\dot{V}O_{2VT2}$ can be interpreted in different ways: An explanation can be found in a rightward shift of $\dot{V}T2$, which indicates improved submaximal performance (14). Regarding the interventions which mainly involved submaximal endurance training, an improvement in submaximal endurance capacity seems reasonable. Nevertheless, only six out of twelve studies investigated $\dot{V}O_{2VT2}$ which indicates that this variable was either unobserved in the past or studies did not publish this variable because of non-significant results. Anyway, the fact that six studies found an improvement in submaximal aerobic capacity after HT in contrast to one study after NT could be considered as a possible indicator for advantages of cLLTH compared to NT.

Table 4

Results of performance variables for hypoxic and normoxic training groups. HT=hypoxic training, NT=normoxic training, N/A=information not available, TTE=time to exhaustion, WR_{max}=maximum wattage, WR_{VT2}=wattage at second ventilatory threshold, ↑=increase, ↓=decrease, ↔=no change, *=significant changes in pre-post comparison (p<0.05).

		Chobanyan-Jürgens et al. 2019	Czuba et al. 2018	Czuba et al. 2011	Debevec et al. 2010	Dufour et al. 2006	Haufe et al. 2008	Holliss et al. 2014	Messonnier et al. 2004	Ponsot et al. 2006	Vogt et al. 2001	Wang et al. 2010	Wiesner et al. 2010
TTE	HT	N/A	N/A	N/A	↑*	↑*	↑	↓	↑	↑	N/A	N/A	↑
	NT	N/A	N/A	N/A	↑*	↑	↑	↑	↑	↑*	N/A	N/A	↑
WR_{max}	HT	↑*	↑*	↑*	↑	N/A	N/A	N/A	↑	N/A	↑*	↑*	N/A
	NT	↑*	↑	↑	↑	N/A	N/A	N/A	↑	N/A	↑*	↑*	N/A
WR_{VT2}	HT	N/A	↑*	↑*	N/A	N/A	N/A	N/A	N/A	N/A	↑*	N/A	N/A
	NT	N/A	↑	↔	N/A	N/A	N/A	N/A	N/A	N/A	↑*	N/A	N/A
Lac_{max}	HT	↑	↑*	N/A	N/A	↓	↔	↓	↑	N/A	N/A	N/A	↓
	NT	↔	↑	N/A	N/A	↑	↓	↓	↑	N/A	N/A	N/A	↓

$\dot{V}E_{max}$ indicates an increase for both groups. Although endurance athletes are known to reach a higher maximum ventilation compared to untrained subjects, maximum ventilation alone has not been described as a direct indicator for endurance capacity in the literature. While Friedmann (2000) declares positive effects of hypoxic induced hyperventilation on performance in hypoxia, benefits on endurance capacity in normoxia still remain unclear. Both, positive effects due to strengthened respiratory muscles as well as negative effects through an elevated energy consumption of the respiratory muscles are conceivable (8, 34). Nonetheless, the small number of studies that found significant results does not allow a distinction between the training methods.

HR_{max} exhibits a decrease in two studies for HT groups. Czuba et al. (2018) explain their finding of reduced maximum heart rate through positive cardiovascular changes. This assumption matches with the results from Zavorski (2000) who investigated changes of HR_{max} after aerobic training. Contrary, some authors assume HR_{max} is an individual value, decreasing with age but being little affected by training status (27). The results showing two studies with decreased HR_{max} after HT and no changes after NT tend to support the hypothesis of an immutable HR_{max} and therefore cannot illustrate differences between HT and NT.

RER_{max} demonstrates an increase in one study after HT. RER_{max} typically is considered as an indicator of maximum exertion during spiroergometric tests (26). Since only four studies examined RER_{max} an interpretation seems inappropriate as a publication bias cannot be ruled out.

For Hb, Hct and Ery none of the studies showed any significant changes. Nonetheless, hematological variables should be interpreted with care, because they can be affected by different circumstances: Hb, Hct and Ery can be influenced by the liquid-supply and changes could be caused by dehydration (23) or altitude-induced diuresis which however, only occurs after 24 to 72 hours in hypoxia (9). Therefore, total hemoglobin mass (tHb) would be a more suitable variable because it is less affected by plasma volume fluctuations (25). However, no study investigated plasma volume or tHb, subsequently, dehydration cannot be ruled out. The small number of studies investigating hematological variables and the lack of significance support the common statement that general LLTH does not cause hematological changes due to an insufficient time in hypoxic environment (8, 29).

Lac_{max} is the only hematological variable for which a study found significant results for HT. It is primary limited by the ability to tolerate lactic acidosis and can be altered by training (11). Therefore, increased lactate values can be explained by higher rates of glycolysis (31). However, the results question the importance of Lac_{max} change by hypoxia.

Regarding TTE, for both training groups two studies found increased values. TTE protocols are commonly used to determine endurance performance. Higher TTE outcomes imply a better endurance capacity. The uniform results indicate similar effects for cLLTH and NT. WR_{max} is increasing in five studies after HT and in three studies after NT. Even though enhancements in performance occur more often after HT, the findings seem consistent with those for TTE. WR_{VT2} augmented in all three studies for HT while only one study found an increase for NT. The rise suggests a rightward shift of $\dot{V}T_2$ and thus an improvement in submaximal performance. Though WR_{VT2} is only investigated in three studies, making selective publication bias a possible limitation, the consistent outcomes of WR_{VT2} seem alike to those of $\dot{V}O_{2VT2}$.

The analysis of the results also raises some difficulties. McLean et al. (2014) already underlined the importance of matching relative training intensities to achieve reliable results. Most studies in this review performed two incremental tests, one in normoxic and one in hypoxic conditions to match relative intensities (4, 6, 7, 10, 12, 19, 24, 30, 33). Chobanyan-Jürgens et al. (2019) stated relative intensities but missed to indicate, whether tests were performed in normoxia or hypoxia. Czuba et al. (2011) and Wang et al. (2010) only tested the endurance capacity in normoxia but tried to reach same relative intensity by lowering the hypoxic intensity. In addition, it should be mentioned that different measurement times after the intervention can lead to inaccuracies of the results. It is noticeable that six out of twelve studies did not indicate the blinding of their intervention (4, 7, 19, 24, 30, 32). Though, there are no obvious connections between study design and study outcome, future studies should consider these details.

Some limitations of the present review ought to be mentioned as well. This review demonstrates solely the changes of pre-post comparison of the investigated studies. Therefore, it is difficult to assess a superiority of either cLLTH or NT as soon as both methods show significant results. ›

Conclusion

The hypothesis that differences between cLLTH and normoxic training become more apparent by looking at a larger number of variables than just $\dot{V}O_2max$ or power output had to be rejected after evaluating the results. The consideration of more variables revealed similarities of $\dot{V}O_{2VT2}$ and WR_{VT2}, but a detection of clear differences between cLLTH and normoxic training was not possible. Nevertheless, this review demonstrates that in future studies also submaximal variables such as WR_{VT2} and $\dot{V}O_{2VT2}$ might be valuable to investigate, as they revealed significant changes in hypoxic training groups for all studies which examined these variables. Thus, it is confirmed that an extended approach can reveal changes in variables, which remained unconsidered in previous reviews.

Despite the limited explanatory power, the present review has added value for current literature on the cLLTH model. It provides an overview of the most common examination variables and offers an orientation for the selection of suitable examination variables in future protocols. ■

Conflict of Interest

The authors have no conflict of interest.

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