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Bachelor's thesis in Human Movement Science
Supervisor: Knut Skovereng
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Kunnskap for en bedre verden

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ABSTRACT

Formål: Denne litteraturstudien ser på hvilken effekt høydetrening har på prestasjon på havnivå. **Metode:** Studier som ble undersøkt er de som så på endringer i fysiologiske aspekter som kan være med på å forbedre prestasjon på havnivå etter treningssamling i høyden som varte i >3 uker på en høyde over havet på >2100 meter. Totalt ble 8 originalartikler inkludert. **Resultat:** Totalt fant fem studier forbedring i prestasjon, hvor forbedringen varierte fra 1,1-4,7%. Fire av seks studier som hadde Vo_{2maks} variabel inkludert viste en forbedring på 1,1-7,3%. Syv av åtte studier fant økning i hemoglobin masse. **Konklusjon:** Basert på hovedfunnene fra artiklene, kan høydetrening muligens øke prestasjonen på havnivå til en viss grad.

Purpose: This literature review investigates the effects of altitude on sea level performance. **Methods:** Studies that were investigated looked at changes in physiological values that can improve performance at sea level after an altitude camp. The camp needed to be >3 weeks and at an altitude of >2100 meters. Eight original studies were included. **Results:** Totally five studies found an improvement in sea level performance, where the improvements varied from 1.1-4.7%. Four out of six studies had Vo_{2max} values included and found an increase of 1.1-7.3%. Seven out of eight studies found an increase in haemoglobin mass. **Conclusion:** Based on the main findings from the articles, altitude training possibly increases sea-level performance to a certain extent.

INTRODUCTION

Altitude training has for many years been used by elite endurance athletes as a supplement in training to get a performance boost at sea level. The research and effects regarding altitude training has been heavily discussed, where some studies have shown a performance enhancement and others have not (Lundby & Robach, 2016). In recent times many elite endurance athletes include altitude training camps into their yearly training plan, in hope of increasing sea-level performance, because some studies have shown that living and training at altitude can lead to a higher maximal oxygen uptake (Vo_{2max}) which is one important physiological factor in endurance sports (Millet & Brocherie, 2020; Muraoka & Gando, 2012). Two other important physiological factors are lactate threshold (LT) and work economy (WE), which some studies have found to be increased by altitude training (Muraoka & Gando, 2012).

When a person ascends to altitude the barometric pressure (P_b) decreases. The lower P_b will lead to a reduced partial pressure of oxygen (PO_2). The reduced PO_2 will then lead to a reduced pressure gradient between the alveoli, blood, and tissue in the body, which will impede the diffusion of oxygen. When the P_b is reduced the body comes in a state called hypoxia, the body will then compensate for the reduced P_b and PO_2 by increasing the breathing rate, which will help reduce the partial pressure of CO_2 in the alveoli (Hoffman, 2014, pp. 377–380).

During acute hypoxia, the body will elevate the cardiac output at rest and during exercise. The elevated cardiac output has shown to increase the resting heart rate by 40-50%, with no change in stroke volume. The elevation of the cardiac output at exercise is also related to an increased heart rate. Unlike what is observed at sea-level during exercise, there is a reduction in stroke volume which has been found to be caused by a reduction in plasma volume (Hoffman, 2014, p. 381). Studies have also shown a decreased maximal heart rate at altitude (Muraoka & Gando, 2012).

Training at altitude has shown to increase the lactic acid levels at any given work rate (WR). The increase in lactic acid levels at any given WR reflects an observed increase in anaerobic metabolism, however when you look at lactic acid concentration after maximum efforts, they are generally reduced compared to maximum efforts at sea level (Green et al., 1989; Sutton et al., 1988).

Exposure to hypoxic conditions causes the tissue in the body to have a lower availability of oxygen, this stimulates the kidneys to release the hormone erythropoietin (EPO), which will stimulate the bone marrow to increase production of red blood cells (RBC) (Sinex & Chapman, 2015). The increase in production of RBC will lead to a higher red blood cell volume (RBCV) and a haemoglobin mass (Hb_{mass}), which may enhance the oxygen delivery capacity from the lungs to the tissue (Muraoka & Gando, 2012; Sinex & Chapman, 2015).

Disregarding resting heart rate and absolute WR lactate, all these physiological adaptations caused by altitude should theoretically be the same caused by endurance training, and by this theory there has been developed three different altitude training strategies: Live high/train high (LHTH), live high/train low (LHTL) and live low/train high (LLTH). The LHTH strategy, also called classic, involves that the athlete will live and train at the same moderate altitude. In the LHTL strategy, athletes live at a moderate altitude and train at a lower altitude or sea level. LLTH strategy involves that the athlete lives at sea-level or low altitude and trains at moderate altitude (Hoffman, 2014, p. 388).

For maximal erythropoietic response it has been found that the athlete(s) needs to live at 2000-2500 meter above sea level, stay there for a minimum of 12-16 hours a day and the training camp to be >3 weeks (Chapman & Levine, 2007; Ge et al., 2002; Sinex & Chapman, 2015). The most popular method among elite athletes in recent years has been LHTL, after a study conducted by Levin et al. (1997), found that by training low athletes did not have to reduce the exercise intensity or workload (Levine & Stray-Gundersen, 1997). By training low, the athlete must train at an altitude < 2000 meter above sea level (Sinex & Chapman, 2015).

As earlier mentioned, research has shown that ascending to altitude will cause haematological changes. The haematological changes can lead to a higher oxygen carrying capacity and this may increase Vo_{2max}. A higher Vo_{2max} will lead to a higher chemical energy potential in the body, and a higher chemical energy potential will lead to a better performance. But if these changes caused by altitude leads to a performance enhancement at sea-level is more uncertain. Therefore, in this literature review we want to further investigate what the effect of altitude training has on sea-level performance in well-trained and elite endurance athletes?

METHODS

The literature search was performed in the search engines Pubmed, Google Scholar and Oria in the period 10.02.22 until 08.03.22. To find relevant literature, we searched for "Altitude training", "endurance athletes" and "sea level performance" that led to 97 searching results and "Altitude training", "Vo2 max" and "sea-level performance" that led to 496 search results. All the search words were used in combination with "OR" and "AND" to make sure to provide a more accurate search. When searching for articles, the title and abstract were used to get an overview of which studies that could be included or not.

These were the criteria for the article to be included: altitude training at 2100 meters or above, at least three weeks of altitude training and that the testing persons are well-trained or elite athletes. If a study used hypobaric chambers (or altitude chamber) the participants had to be inside the hypobaric chamber for at least 12 hours per day for the article to be included. The subjects needed to be defined as either well-trained (Vo_{2max} of <60 mL/kg/min) or elite (Vo_{2max} of <70 mL/kg/min) endurance athletes. If a study did not include Vo_{2max} variables, the subjects needed to be members of a national team and/or represent their country in the Olympics and/or at the World Championships to be included. We excluded all review articles, meta-analysis or articles that only focused on the haematological response.

RESULTS

The search for literature resulted in eight articles, from several different endurance sports. All included articles had their research background from either Europe, Australia, North or South America. Results from the articles are conducted into Table 1 where each study will be described in more detail.

Table 1: Characteristic of the original articles

Main author and year	Level and sport(s)	Number of participants	Study design	Duration altitude	Results
Robach, Paul, 2018.	Well trained cross-country skiers	16 men 3 women	**Case control** 1) LHTL: Living at 2207 m 2) Control group: Living at 1035 m Both groups trained at 550-1500 m (21% of the time at 500 m, 44.2% at 550-800 m, 16.6% at 800-1100 m and 18% at 1100-1500 m) in Chamonix, France.	26 days	**<u>Group 1: LHTL</u>** The LHTL group saw an improvement of 21s in the 3000 m time-trial from 650s ± 63 to 629s ± 66 (3.8 ± 4.4 % improvement) and an increase in Vo_{2max} from 68.9 ± 5.5 to 72.4 ± 7.3 ml·kg−1·min−1 pre- to post-altitude. **<u>Group 2: Control group</u>** The control group saw an improvement of 20s improvement in the 3000 m time trial from 633s ± 58 to 613s ± 59 (3.1 ± 6.6 % improvement) and an increase in Vo_{2max} from 69.6.4 ± 5.3 to 73.8 ± 5.1 ml·kg−1·min−1 pre- to post-altitude.
Stray-Gundersen, James, 2001.	Elite runners	14 men 8 women	**Cohort study** Living at 2,500 m in Deer Valley, USA while performing high-intensity training at 1,250 m Salt Lake City, USA.	27 days	The sea-level 3000 m time-trial significantly improved 5.8s s (95% confidence limits 1.8–9.8 s) or 1,1% (95% confidence limits 0,3%-1,9%). Three athletes improved their 3000 m time-trial by as much as 23s, however one athlete increased in time and ran 18s slower than pre-altitude. The Vo_{2max} group average increased significantly by an average of 3% (P<0.05 from 72.1 ± 6.9 ml·kg−1·min−1 to 74.4 ± 6.8 ml·kg−1·min−1 when comparing Pre-HiLo to Post-HiLo.
Wehrlin, P. Jon, 2006.	Well trained orienteering and cross-country skiers	7 men 9 women	**Case Control** 1) LHTL group: Living 18 h/day at 2456 m and training at 1800m and 1000 m above sea-level in the Swiss Alps. 2) Control group: Living and training between 500 m and 1600 m above sea-level in the Swiss Alps.	24 days	**<u>Group 1: LHTL</u>** The athletes improved 5000 m time-trial with ∼ 18 s (1.6%; $P < 0.05$). Vo_{2max} increased for women (50.8 ± 2.1 vs. 54.5 ± 2.8 ml·kg−1·min−1) and men (62.3 ± 5.2 vs. 63.8 ± 5.5 ml·kg−1·min−1) ($P <$ 0.05, women and men together) when comparing pre- and post-altitude. **<u>Group 2: Control group</u>** Only haematological responses were included for this group.
Gore, Chris, 2013.	Elite cyclist	8 men	**Cohort study** Living at 2690 m above sea-level in Toluca, Mexico. Training between 1850 and 4578 m. The training rides were as high as 4578 m for 1.5 hours, while being as low as 1850 m for 9 hours.	31 days	The group total work for the 5-minute maximal test was unchanged for the three measurements post-altitude. There were no significant changes in average Hr, W, W/kg candace, or difference in their worst performance in the post camp tests (-2.4%, t=1.04, p=0.32). There was however a significant increase in total work in their best performance in the post camp tests (+4.3%, t=-3.57, p=0.009, effect size=1.26). Vo2max was not significantly improved.

Gough E, Clare, 2012.	National team swimmers (elite)	15 men 11 women	**Randomized control trial** 1) LHTL: Living at 3000 m in normobaric hypoxia and training at their normal environment in Canberra, Australia at 600 m. 2) LHTH (Classic group) Living and training at Sierra Nevada, Spain, 2,320 m (5 swimmers), and Flagstaff, USA, 2,135 m (12 swimmers). 3) Race control group: Australian world championship swimming team that was collected from the internet.	21 days	Found some unclear results for the LHTL group and Classic group. In the World championship the altitude groups performed "most likely" a faster time at the National Championships post-altitude (mean percent change ± 90% CL: -0.8 ± 0.6%). The non-altitude group (race control) "very likely" performed a faster race (-1.1 ± 0.6%) at the World championship compared to the National Championship. However, swimming performance at day 14 and day 28 after altitude training were no different when comparing it to pre-altitude results, so no clear advantage was indicated for the subjects that completed altitude training in the season-long comparison.
Sharma, P. Avish., 2018.	Elite runners	6 men 2 women	**Observational case study design** Living and training at Flagstaff, USA, 2135 m above sea-level.	21-28 days	Seven of eight athletes had their personal best results within 8 days after the altitude training with an overall improvement of 1.1 ± 0.7%, p = 0.2, d = 0.05. Athlete number eight did not compete before 57 days after the altitude training, however this person also achieved lifetime best results.
Rodriguez. A. Ferran, 2015.	Elite swimmers	27 men 34 women	**Controlled, nonrandomized, four parallel groups trial** 1) High-High: Living and training at 2320 m in Sierra Nevada, Spain. 2) High-High3: Living and training at 2320 m in Sierra Nevada, Spain for three weeks instead of four. 3) High-High/Low: Living at 2320 m in Sierra Nevada, Spain, and training at both moderate and low altitude (690m) in Granada, Spain. 4) Low-Low: Living and training nearby sea-level in Sabadell (190 m) and/or Madrid (655 m).	28 days	**Group 1 (High-High):** The 100/200-m (sprinters 100-m / non sprinters 200-m) personal best stroke (**TT 100/200)** was improved -3.4%; (±1.0%; *P* < 0.001) and the 400-m front crawl (**TT400)** was improved -3.3%; (±1.3%; *P* < 0.001). **Group 2 (High-High3):** The 100/200-m (sprinters 100-m / non sprinters 200-m) personal best stroke (**TT 100/200)** was improved -3.1%; (±0.9%; *P* < 0.001) and the 400-m front crawl **(TT400)** was improved -3.3% (±1.3%; *P* < 0.001). **Group 3 (High-High/Low):** The 100/200-m (sprinters 100-m / non sprinters 200-m) personal best stroke (**TT 100/200)** was improved -6.3%; (±1.2%; *P* < 0.001) and the 400-m front crawl (**TT400)** was improved -4.7%; (±1.1%; *P* < 0.001). **Group 4 (Low-Low):** The 100/200-m (sprinters 100-m / non sprinters 200-m) personal best stroke (**TT 100/200)** was improved -3.7%; (±1.0%; *P* < 0.001) and the 400-m front crawl (**TT400)** was improved -1.6%; (±1.0%; *P* < 0.001). Vo_{2max} did not significantly improve in any of the groups.
Levine, D, Benjamin, 1997.	Well-trained runners	27 men 122 women	**Randomized controlled trial** 1) High-low': Living at 2,500 m and training at 1,250-1,400 m above sea-level in Salt Lake City, USA. 2) High-high: Living and training at 2,500-2700 m above sea-level in Deer Valley, USA. 3) Low-low: Living and training in a mountain environment at sea level (150 m) in San Diego, USA.	28 days	**Group 1: High-Low**: Improvement in 5000 m time-trial by 13.4s ± 10s and 5% improvement in Vo_{2max}. **Group 2: High-High:** Slower 5000 m time-trial by 3.3s ± 9s and 5% improvement in Vo_{2max}. **Group 3: Low-Low:** Slower 5000 m time-trial by 26,7s ± 13s and no improvement in Vo_{2max}.

Performance

Overall, the five studies (Gore et al., 1998; Sharma et al., 2018; Stray-Gundersen et al., 2001; Wehrlin et al., 2006; Levine & Stray-Gundersen, 1997) found an increase in sea-level performance and showed an overall improvement of between 1.1-4.7% in the sea-level time-trial. Stray-Gundersen et al. (2001), Levine & Stray-Gundersen (1997) and Wehrlin et al. (2006) found a significant improvement in LHTL, while Sharma et al. (2018) and Gore et al. (1998) both showed a significant improvement for the LHTH groups. The last three studies (Gough et al., 2012; Robach et al., 2018; Rodríguez et al., 2015) found an improvement in sea-level performance for both altitude group(s), but they also found approximately the same improvement in the control group(s).

Well-trained vs Elite

Among the studies that included elite-athletes (Gore et al, 1998; Gough et al, 2012; Rodríguez et al, 2015; Sharma et al, 2018; Stray-Gundersen et al, 2001) four out of five studies found an effect on performance. For the studies of elite athletes, three included Vo_{2max} results (Gore et al, 1998; Rodríguez et al, 2015; Stray-Gundersen et al, 2001) with two finding no effect on Vo_{2max}. The three studies that included well-trained athletes (Levine & Stray-Gundersen, 1997; Robach et al., 2018; Wehrlin et al., 2006), two studies, Levine & Stray-Gundersen and Wehrlin et al. found an increase in both performance and Vo_{2max}. Levine & Stray-Gundersen (1997) also found a significant difference between the altitude group and control group. Robach et al. (2018) also found an increase in both performance and Vo_{2max} for the LHTL group, however approximately the same results were found in the control group.

Performance determining variables

Six studies performed a Vo_{2max} test, where four studies found an improvement when comparing pre and post altitude variables. The studies that showed an improvement in Vo_{2max} (Stray-Gundersen et al., (2001); Wehrlin et al., (2006); Robach et al., (2018); Levine & Stray-Gundersen, (1997)) using the LHTL method and found an overall improvement of 1.1 - 7.3%. Gore et al. (1998) (LHTH) and Rodriguez et al. (2015) (all groups) found no significant improvement within the groups and the overall changes in Vo2-max were calculated to -2.8 - 1.9%.

As mentioned earlier, ascending to altitude will lead to some haematological changes, with the studies showing the expected psychological effects; an increase in Hb_{mass} was found in seven out of eight studies for altitude groups, with an overall improvement between 1.2 - 9.7%. Gough et al. (2012) were the only study not to find an increase in Hb_{mass} for the altitude group.

DISCUSSION

The purpose of this literature study was to identify what effect altitude training (>3 weeks) has on sea-level performance for well-trained and elite endurance athletes. The main finding was improved performance and Vo_{2max} in the majority of the studies with larger effects seen for the physiological measures. If these studies reflect on true causal relationships, it can mean well-trained and/or elite endurance athletes can improve sea-level performance by training in altitude for >3 weeks. However, three studies showed no significant improvements in sea-level performance when compared to a sea-level control group.

Performance

The studies were categorized as either well-trained or elite endurance athletes by the group average Vo_{2max} values, opening for discussion of the different group's changes in performance. When including both well-trained and elite endurance athletes the results for performance can be interpreted differently, because of elite athletes' higher Vo_{2max} values, each percent increase in performance might be more difficult to achieve in comparison to well-trained athletes, due to the elite athletes already being closer to their psychological ceiling, also called the ceiling effect. Ceiling effect might occur for an athlete or group when the psychological variables are heading towards the best score possible, resulting in a more challenging task to achieve a significant improvement in performance (Faber & Fonseca, 2014).

In four of the studies (Levine & Stray-Gundersen, 1997; Robach et al., 2018; Rodríguez et al., 2015; Sharma et al., 2018), there were some kind of taper after or in the last week of the altitude or sea-level training camp. The training data from Gore et al. (1998) and Gough et al. (2012) showed that there was no form of taper under or after the camp. The lack of taper might have affected the performance results since Gough et al. (2012) found no significant improvement in performance. Gore et al. (2012) found no significant improvements when you looked at the group results at the different test days, it was only when you looked at the best result for each individual at any given test day, that there was found a significant improvement compared to the baseline data. On the other hand, the performance enhancement seen in the other studies may be because of this taper. For instance, in the study of Sharma et al. (2018) there was a reduction of 43% in training load (TL) and 30% in training volume (TV) for the seven athletes that competed eight days after the camp. Levin & Stray-Gundersen (1997) also had a reduction in TV of 30%. A reduction in TV and TL can in themself be the reason for the athlete's personal record performance. To illustrate, the review article of Muijka et al. (2004) found a performance increase of 1.4% in highly trained swimmers, 1.5% in cross-country runners and up to 3% in marathon runners after reduction in TL and/or TV. The rest of the studies, except Wehrlin et al. (2006) and Stray-Gundersen et al. (2001) which did not include any training data, did not mention how much of a reduction there was in TL and/or TV, only that it was a taper into the testing period.

More often elite athletes have training and performance as their full-time job, while well-trained athletes more often must combine it with a day-time job, study or maybe both. At an altitude/training camp, surrounded by several athletes and professionals in the field with a common goal in improving performance, there is a huge opportunity to focus on training, as well as the key details beside training. Elite athletes might be more exact in the details in- and beside training like resting/sleeping enough, changing to dry clothes straight after training, getting the right nutrition as well as controlling/varying the intensity of training. For well-trained athletes, the altitude camp might raise awareness of the smaller details, leading to a positive effect of the training camp regardless of altitude.

Wehrlin et al. (2006), Rodriguez et al. (2015), Robach et al. (2018) and Levine & Stray-Gundersen (1997), all had control groups included to compare the outcome from the altitude group(s), with the main focus to find out if altitude training results in a higher percent increase in sea-level performance, compared to only training at sea-level for >3 weeks. Specifically, Robach et al. (2018) and Gough et al. (2012) found approximately the same increase in the control group for performance (sea-level time trial results), Vo2max (only in Robach et al., 2018) and haematological response after the interventions. The assumed improvement in the LHTL groups, due to altitude training, was seen as an absolute bias when the control groups experienced almost identical improvement, resulting in a training effect rather than an effect of altitude.

The positive effects of an altitude training camp that is found in some of the studies may not be because of training at altitude but because of the training camp itself. In most of the studies that have a control group(s), they are located at different geographical locations far away from each other. To illustrate, the altitude and control group(s) in Levin & Stray-Gundersen (1997) are located >1000 km apart and Rodriguez et al. (2015) had the control- and LHTL-group located in Australia and two LHTH-groups located in either Spain or USA. The only study that has the separate groups located at the same place is Robach et al. (2018), where the two groups trained together in Chamonix, France and the only difference was that the LHTL-group lived at altitude and the control-group lived further down the valley. In the study of Robach et al. (2018) the altitude and control group had the same training effect after the training camp. The different location can lead to dissimilar living and training conditions that may influence the test results. For instance, in the Levin and Stray-Gundersen (1997) study, the control group had an increase in 5000 m time after the camp and one reason for this increase may be because of the heat in Dallas where the tests were conducted, and they were used to train in a cooler climate in San Diego.

The risk vs reward of altitude training is probably not that good, because related to altitude there are a lot of risks that might negatively affect the development of the athlete's performance. Altitude training is an expensive training form compared to training at sea-level and it might lead to a bigger risk of illness and overtraining caused by the bigger physiological stress of staying at altitude. The risk of illness (due to physiological stress) and overtraining (due to regulation in TL and TV) is related to any athletes, however by increasing the risk of these in altitude might not be beneficial for athletes that try to increase their sea-level performance.

There has been some discussion around responders and nonresponders in altitude training. For instance, Chapman et al (1998) used the data from the Levin & Stray-Gundersen (1997) study to investigate what separated the ones that responded to altitude training and those who did not. The difference between the responders and nonresponders was related to two things, physiological changes related to altitude acclimatization and an effect of training, and Chapman et al (1998) concluded that athletes that do not respond to altitude training, should rather train at or close to sea-level. However, it has been found that an athlete can respond differently to two different altitude camps (McLean et al., 2013; Nummela et al., 2021), so it might not be as easy as just looking at the response of an athlete after just one altitude camp like Chapman et al. (1998). The difference in response can fluctuate from one altitude camp to another, with a risk of the athlete not experiencing the same outcome each time.

Performance Determining Variables

Altitude training has shown to cause some haematological changes, and as mentioned earlier there might be a connection between haematological changes, caused by altitude, and changes in Vo_{2max}. Hb_{mass} increased in seven out of eight of the studies, while Vo_{2max} only increased in four of the six studies that included these variables.

Gore et al. (1998) was the only study to not improve in Hb_{mass}, and that might be the reason there is no increase in Vo_{2max} in this study. The lack of increase in Hb_{mass} and Vo_{2max} for the athletes was not due to an inadequate altitude stimulus, with the group implementing training up to 4578m, while living at 2690 m above sea-level. However, the lack of increase in performance determining variables in Gore et al. (1998) might be due to the already high baseline values or/and excessive training load that led to illness during the training camp.

Rodriguez et al. (2015) found no significant improvement in Vo_{2max}, however the time-trial improved in all groups. The improvement in performance was not related to changes in Vo_{2max} or Hb_{mass}, so the improvement may be related to other mechanisms than enhanced oxygen delivery capacity. The increase in performance may be related to an increase in WE and/or LT, because there was found an improvement in maximal steady state in the study of Levin & Stray-Gundersen (1997) in the LHTL-group, and it has been found that altitude training may increase WE and LT in the review article conducted by Muraoka & Gando (2012). However, the increase Rodriguez et al. (2015) found in performance was found in all groups, so the increased WE and LT could be related to the training itself and not altitude. Robach et al. (2018) also found improvement in WE and LT, and this was also found in both groups, which indicates that this might be related to training itself.

Limitations of Studies

The included studies have some weaknesses that can affect the outcome of the results. One of the clear weaknesses is that some of the studies have small sample sizes, where two of the studies (Gore et al., 1998; Sharma et al., 2018) included a sample size of < 10. A smaller sample size can lead to one athlete having a larger impact on the average results. By surveying larger samples, the overall results can be seen as a more realistic indicator for well-trained and elite endurance athletes that consider implementing altitude training. However, large samples can also bring along some negative effects, as minor differences might be transformed into significant differences even though they actually are clinically insignificant (Faber & Fonseca, 2014). As a result, both small and large samples can affect the results leading to a misguided in the total scope of the results.

The lack of control group in (Gore et al., 1998; Sharma et al., 2018; Stray-Gundersen et al., 2001) might be a limitation. The absence of a control group might lead to a weakening in the researcher's ability to draw a conclusion, as the results might not be because of training at altitude by its own, rather a combination of several varied factors. Therefore, further researchers should be implemented with control groups, preferably on elite athletes and to an extent of the same geographical location.

CONCLUSION

Most of the studies showed an increase in sea-level performance after altitude training, but with three studies showing the same result in both altitude and control group, makes the conclusion more uncertain. The five studies showing an improvement in performance did not include a control group, making them less certain that altitude training improves sea-level performance. Based on the main findings in the eight articles, it can be concluded that altitude training might increase sea-level performance to a certain extent.

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