Fontys, University of Applied Sciences
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Bachelor thesis

Can inspiratory muscle training increase exercise tolerance in endurance athletes by increasing maximal and submaximal exercise capacity?

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Preface

This report is the final product of the graduation process of the four year studies of Physiotherapy. The topic baseline (Inspiratory Muscle Training in Endurance Athletes) was provided by the school; further specialisation was done by the students. This led to the question: ‘Can inspiratory muscle training increase exercise tolerance in endurance athletes by increasing maximal and submaximal exercise capacity?’

In medical professions Inspiratory Muscle Training is a well known tool incorporated in treatment with COPD patients however it is not as well known as a means to improve exercise tolerance in endurance athletes. Various studies have been done on the actual effect of Inspiratory Muscle Training in endurance athletes but no uniform conclusion has yet been drawn. A good way of integrating different outcomes in one study is a literature review that looks at the different study designs and outcomes in order to research whether Inspiratory Muscle Training does have an effect on exercise tolerance which is done in this review.

Even though students were responsible for their own work guidance by school was provided. I would like to specially thank the Graduation Project Coordinator and my general supervisor Chris Burtin for all the support and guidance throughout this process. Great appreciation also goes to my fellow students who reviewed my work next to their own assignments.

Sabrina Krusekamp

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Article

Can Inspiratory Muscle Training increase exercise tolerance in endurance athletes by increasing maximal and submaximal exercise capacity?

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Abstract

Background: Inspiratory Muscle Training is a well known tool used for treatment in COPD. Proven to improve endurance in patients suffering from this condition the question arises if this effect could be transferable towards healthy individuals. Athletes could benefit from improved performance if Inspiratory Muscle Training does have an effect on exercise tolerance. The purpose of this study was to evaluate if maximal and submaximal endurance capacity can be improved by Inspiratory Muscle Training in endurance athletes.

Research question: Can Inspiratory Muscle Training increase exercise tolerance in endurance athletes by increasing maximal and submaximal exercise capacity?

Goal: The purpose of this study was to investigate whether Inspiratory Muscle Training can be of use in an endurance athletes' training regimen in order to improve exercise tolerance.

Method: A literature review was done by analyzing Randomized Controlled Trials and Cohort Studies. Only endurance athletes were part of this review. PEDro and SIGN scales were quality assessment tools for the included articles. Outcomes that were looked at included VO2max, submaximal measures, peak work and subjective ratings of effort and dyspnea.

Results: Out of 132 articles, five proved to be relevant for this review. All five were of acceptable and high quality. VO2max, VO2 and heart rate showed no significance in between and in within groups. Inconclusive findings were found for peak work and subjective ratings.

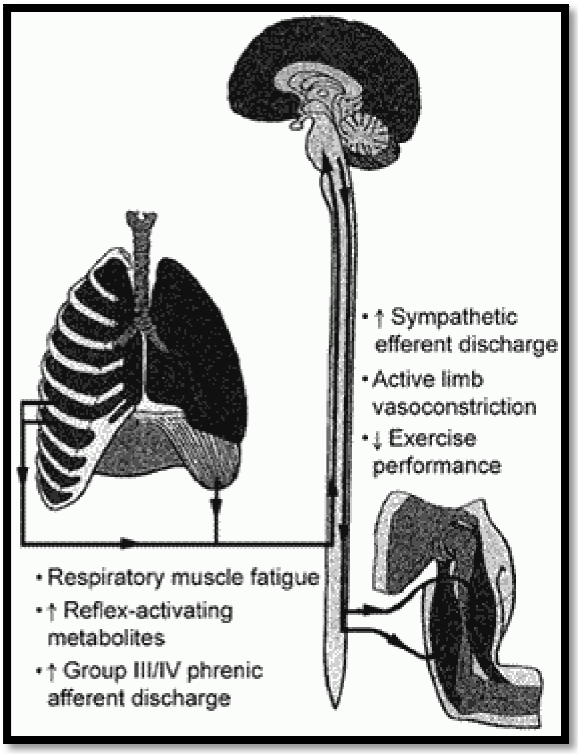
Conclusion: No significant improvements could be found for VO2max and submaximal indicators. Inconclusive findings were found for peak work and subjective ratings of effort and dyspnea.

1. Introduction

Endurance training is a very popular and common exercise in our society. 65% of all people participate in regular exercise in Australia [5]. Endurance training can benefit cardiovascular fitness and help in decreasing body fat [13] and makes it therefore a popular sports. Endurance training is not only used as a leisure sports activity but also competitors like marathon runners or triathletes as well as professional athletes (swimmers, rowers, cyclists, etcetera) require a high demand of endurance in order to perform on a level that makes it possible to compete internationally.

Trainers and sports coaches come across clients that would like to take their current physical abilities to a higher level. In order to improve the physical capabilities, use of different (sports-specific) training modalities are made. These include training principles like Interval Training, Long Slow Distance (LSD) and the most recent popular High Intensity Interval Training (HIIT).

Training adaptations related to endurance training are well known. Endurance training by itself can already improve aerobic fitness by increasing VO2max as well as the overall endurance [16]. But with any person, athletic or not, overall fatigue will set in sooner or later. As Romer and Polkey reported maximal exercise causes respiratory muscles (diaphragm and abdominals) to fatigue. They related this fatigue to the competition in blood supply between respiratory muscles and locomotor muscles [11]. This might be one of the factors contributing to overall exhaustion. When the respiratory muscles fatigue, neurological changes cause the arteries to constrict so the oxygen transport decreases which causes the muscles to fatigue since their oxygen supply is decreased [6,14]. This is known as the metaboreflex. In order to prolong the start of this cycle one could wonder if the elongation of the time before the respiratory muscles fatigue would help to increase the overall performance and if there is another scope of training, more specific, that could increase the respiratory muscular endurance.



A study conducted by Harms et al in 2000 [3] showed that unloading of inspiratory muscles had a positive effect on the exercise tolerance related to endurance and VO2max whereas extra load on inspiratory muscles had the opposite effect.

Respiratory muscle training is a well known treatment principle in patients with Chronic Obstructive Pulmonary Disease (COPD).Research has shown inspiratory muscle training in COPD patients is useful for increasing exercise capacity and endurance [2].

With this research and the effect of Inspiratory Muscle Training in COPD patients in mind one could wonder if strengthening inspiratory muscles would have the same effect as the respiratory muscle unloading in healthy subjects to increase their athletic performance and thereby improve physical performance concerning VO2max and endurance by the use of inspiratory muscle training. If differences can be seen between athletes that include inspiratory muscle training and athletes that do not, implementing inspiratory muscle training into an athlete’s training regimen could be of major importance to achieve maximum results.

2. Method

2.1 Criteria

Inclusion and Exclusion criteria had to be established in order to select compatible articles that would be relevant for this review before starting article research. Figure 1 includes all inclusion and exclusion criteria applicable for this review.

Figure 1

Inclusion	• Subjects that are endurance athletes including runners, cyclists, swimmers and rowers • Subjects of all age groups • Articles that have been published between 2000 and 2013 • Randomized controlled trials • Cohort Studies • English written articles
Exclusion	• Sedentary subjects • Wheelchair bound athletes • Inspiratory muscle training for less than four weeks

Subjects

Articles that contained endurance athletes namely runners, cyclists, swimmers or rowers were included. Subjects that were wheelchair bound athletes or not physically active as well as athletes that did not involve in the previously stated sports were excluded.

Study Types

Focus was set on Randomized Controlled Trials and Cohort Studies. Other studies like Systematic Reviews as well as Expert Opinions and Case Studies were excluded.

Intervention

Intervention, in this case Inspiratory Muscle Training, had to be at least four weeks in order to be included. Inspiratory Muscle Training could be either focusing on strength or endurance.

Articles

Articles published before 2000 were excluded in order to only incorporate the latest research.

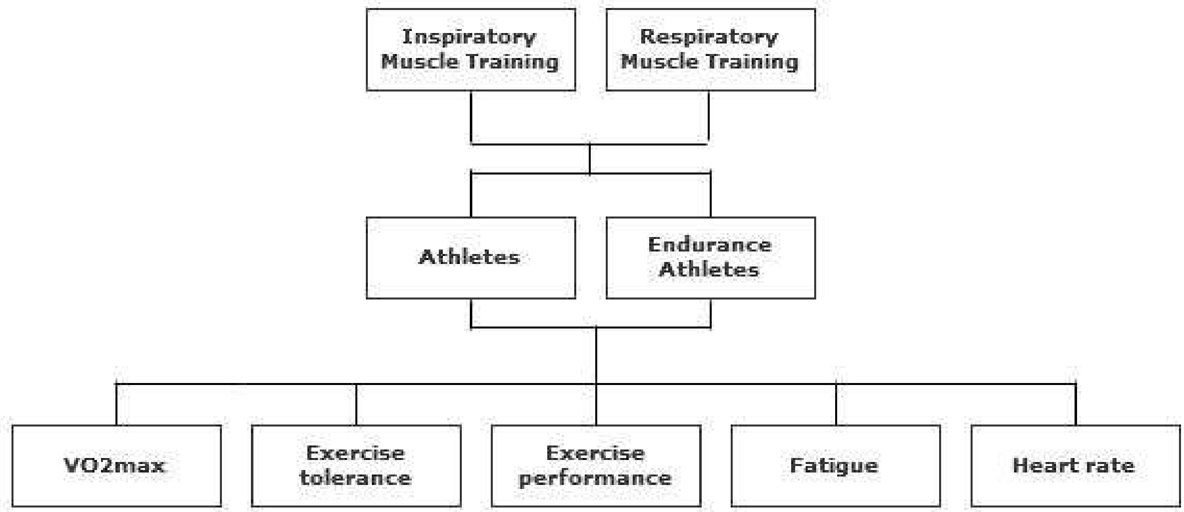
2.2 Databases

Three scientific databases were chosen in order to research articles that could be used for this review. PubMed which accesses the MEDline database, SPORTDiscus which is part of EBSCOhost and PEDro. The databases were accessed in week 14, 2013.

2.3 Keywords

Keywords used were either ‘Inspiratory Muscle Training’ or ‘Respiratory Muscle Training’ combined with the search terms ‘Athletes’ or ‘Endurance Athletes’ as well as ‘VO2max’, ‘Heart rate, ‘Exercise Tolerance’, ‘Exercise Performance’ and ‘Fatigue’ (Figure 2).

Figure 2



2.4 Selection Procedure

Articles were scanned by their title and abstract in order to see if they were relevant for this review. If eligibility was given the full text article was read and scanned with the previously mentioned in- and exclusion criteria. Any irrelevant articles were excluded. Furthermore included articles were analysed with the so called snowball principle which incorporates reading through the references and looking for articles that could be used in this review.

Outcome measures included VO2max, submaximal VO2, heart rate, peak work and subjective ratings on dyspnea and effort.

2.5. Quality Assessment

Quality of Randomized Controlled Trials was analysed using the PEDro scale. The PEDro scale is a tool to analyse eleven criteria of Randomized Controlled Trials including *randomization*, *blinding*, *group similarity at baseline* as well as *statistical comparison and measures of key outcomes*. The first item is not enumerated so ten criteria are scored. Classification is done by the cut off scale and is as followed: 0-6 points = low 6-10 = high [6].

Cohort studies were analysed by the SIGN checklist. This checklist focuses on validity and bias by looking at *selection of subjects*, *assessment* and *confounding factors*.

2.6. Data Extraction

Data on subjects, intervention and outcome was extracted using a data extraction table created in Microsoft Office Excel 2007 in order to get an overview and compare the different interventions and outcomes of each study (Appendix 1).

2.7 Best Evidence Synthesis

Level of evidence was analysed with the NHMRC Evidence Scale. This scale includes four levels (I, II, III, IV) of evidence with number three divided into three which sums it up to a total of six. The higher the score, the better the level of evidence is, the more reliable the study gets.

Table 1: NHMRC Evidence Hierarchy

Level	Intervention [1]	Diagnostic accuracy [2]	Prognosis	Aetiology [3]	Screening Intervention
I [4]	A systematic review of level II studies	A systematic review of level II studies	A systematic review of level II studies	A systematic review of level II studies	A systematic review of level II studies
II	A randomised controlled trial	A study of test accuracy with: an independent, blinded comparison with a valid reference standard,[5] among consecutive persons with a defined clinical presentation[6]	A prospective cohort study[7]	A prospective cohort study	A randomised controlled trial
III-1	A pseudorandomised controlled trial (i.e. alternate allocation or some other method)	A study of test accuracy with: an independent, blinded comparison with a valid reference standard,[5] among non-consecutive persons with a defined clinical presentation[6]	All or none[8]	All or none[8]	A pseudorandomised controlled trial (i.e. alternate allocation or some other method)
III-2	A comparative study with concurrent controls: ▪ Non-randomised, experimental trial[9] ▪ Cohort study ▪ Case-control study ▪ Interrupted time series with a control group	A comparison with reference standard that does not meet the criteria required for Level II and III-1 evidence	Analysis of prognostic factors amongst persons in a single arm of a randomised controlled trial	A retrospective cohort study	A comparative study with concurrent controls: ▪ Non-randomised, experimental trial ▪ Cohort study ▪ Case-control study
III-3	A comparative study without concurrent controls: ▪ Historical control study ▪ Two or more single arm study[10] ▪ Interrupted time series without a parallel control group	Diagnostic case-control study[6]	A retrospective cohort study	A case-control study	A comparative study without concurrent controls: ▪ Historical control study ▪ Two or more single arm study
IV	Case series with either post-test or pre-test/post-test outcomes	Study of diagnostic yield (no reference standard)[11]	Case series, or cohort study of persons at different stages of disease	A cross-sectional study or case series	Case series

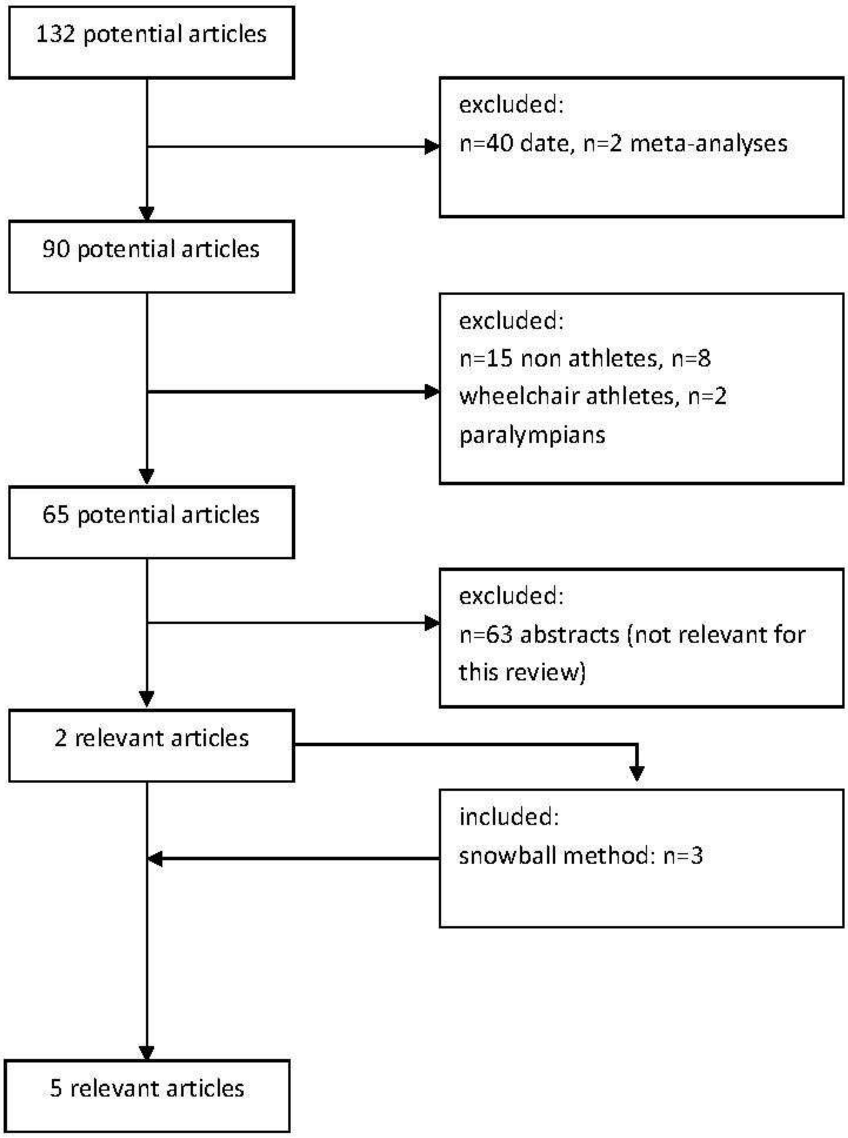
3. Results

3.1 Search String

132 potential articles were found using the previously mentioned search terms. Refining the search by date, type of research and contents, two relevant articles were included. By researching the articles' references for further relevant studies, and by using the snowball method, another three articles were discovered which sums up the included articles to a total of five.

Figure 3 contains a detailed summary of the search string.

Figure 3



3.2 Quality Assessment

Table 2 shows the results of the assessment of the articles using the PEDro scale for Randomized Controlled Trials and the SIGN checklist for the Cohort study (Appendix 2). As well as the best evidence synthesis using the NHMRC scale. All Randomized Controlled Trials were of high quality with a II score in NHMRC while the Cohort study was of acceptable quality with a score of III-2.

Table 2

Author	PEDro/SIGN score	Quality of article	NHMRC
Romer et al. [12]	7/10	High	II
Sonetti et al. [15]	8/10	High	II
Williams et al. [17]	+	Acceptable	III-2
Inbar et al. [4]	7/10	High	II
Riganas et al. [10]	6/10	High	II

3.3 Subjects

While Romer et al. [12] and Sonetti et al. [15] only used male subjects, Williams et al. [17] and Riganas et al. [10] used both male and female. Inbar et al. [4] did not specify any gender in his research. Intervention and control/placebo groups were of equal or nearly equal size in four of the five researches ranging from eight to eleven athletes. Since Williams et al. [17] is a cohort study it does not include a placebo or control group and makes use of an intervention group with seven subjects. The mean age lies between 20.9 years old in Williams et al.'s [17] research, up to 30 years old in Romer et al.'s [12] research. All other subjects within the researches lie within this age range. All five trials only contain endurance athletes. Romer et al. [12] and Sonetti et al. [15] include cyclists as subjects, while Williams et al. [17] and Inbar et al. [4] accommodate runners whereas Riganas et al. [10] look at rowers.

3.4 Interventions

Duration of interventions ranges from four [17] to ten weeks [4]. Romer et al. [12] and Riganas et al. [10] trained for six weeks while Sonetti et al. [15] trained for five.

One of the two devices used in the six studies was POWERbreathe. Romer et al. [12] and Sonetti et al. [15] both used the setting of 50% of the maximal inspiratory pressure during training. Romer et al. [12] assigned 30 repetitions twice a day over the whole period of the trial. Sonetti et al. [15] made the subjects train until task failure, which means repetitions were dependent on each subject individually.

After each training with the POWERbreathe Sonetti et al. [15] also implemented hyperpnea training using all effort dynamic respiratory muscle work, increasing the depth with every breath for 30 minutes. Training was set five times per week.

Subjects in the placebo groups participating in Romer et al.'s [12] research also used the POWERbreathe device but resistance level was set at 15% with 60 repetitions exerting slow protracted breaths. Sonetti et al.'s [15] placebo group made use of a placebo breathing device which required 30 minutes of normal breathing.

The second device used by Williams et al. [17] and Inbar et al. [4] is a Threshold trainer. Williams et al. [17] used 50% of the maximal inspiratory pressure in the first week progressing five percent each week doing four to five minutes training for five to seven sets with one to two minutes breaks in between four to five times a week. Inbar et al. [4] used 30% of the maximal inspiratory pressure during the first week increasing five percent each session until the end of the fourth week and from week five on continuing with 80% six times per week. Inbar et al.'s [4] placebo group received the same training but with no resistance using the threshold trainer.

Riganas et al. [10] does not specify the training device used but does give specific settings. The start point is at 30% of the maximal inspiratory pressure increasing five percent each time up to 80% continuing that resistance for another four weeks. Breathing frequency is at a self selected pace. Training is done for 30 minutes which is made up of five to seven sets of four to five minute sessions five times a week. The control group does not get an intervention.

3.5 Outcomes

A summary of significance between groups and within group are outlined in Table 3 and 4. While VO2max, submaximal VO2 at different workloads and heart rate all show no significant changes between and within groups, peak work and subjective ratings show contradictive findings.

Table 3

Author	PEDro/SIGN	Outcome measure (between groups)				
		VO2max	VO2	HR	Peak work	Subjective
Romer et al. [12]	High		Not significant	Not significant	Significant	Significant
Sonetti et al. [15]	High	/		Not significant	Not significant	Not significant
Williams et al. [17]	Acceptable	Not significant	Not significant	Not significant		Not significant
Inbar et al. [4]	High	Not significant		/		
Riganas et al. [10]	High	Not significant				Not significant

Table 4

Author	PEDro/SIGN	Outcome measure (within groups)				
		VO2max	VO2	HR	Peak work	Subjective
Romer et al. [12]	High		Not significant	Not significant		
Sonetti et al. [15]	High	Not significant		Not significant	Significant	Not significant
Williams et al. [17]	Acceptable	Not significant	Not significant	Not significant		Not significant
Inbar et al. [4]	High	Not significant		Not significant		
Riganas et al. [10]	High	Not significant				Not significant

3.5.1 VO2max

Table 5

Author	Group	VO2max before	VO2max after	In between groups	Within groups
Sonetti et al. [15]	I	55.0 ± 5.0	56.5 ± 7.3		P>0.05
	P	54.2 ± 2.5	54.1 ± 4.0		P>0.05
Williams et al. [17]	I	59.9 ± 11.7	app. 60 ± 10		P>0.05
Inbar et al. [4]	I	58.0 ± 4.6	58.1 ± 5.4	P>0.05	P>0.05
	C	61.2 ± 4.7	59.7 ± 7.1		P>0.05
Riganas et al. [10]	I	app. 52.0 ± 6.0	app. 52.0 ± 6.0	P>0.05	P>0.05
	C	app. 51.5 ± 6.3	app. 52.0 ± 8.0		P>0.05

I: Intervention P:Placebo C:Control, app.: approximately

VO2max values were included in four out of five articles (Table 5). Significant in between groups changes could not be found in Inbar et al.'s (4) and Riganas at al's (9) researches. Sonetti et al. [15] does not report interaction effects on VO2max measurements. Even though slight increases were seen in Sonetti et al. [15], Williams et al. [17] and Inbar et al.'s [4] researches, the changes were not statistically significant with p-values all above 0.05 in both Intervention and Control/Placebo groups. An indication of significant difference in change in VO2max could not be found in Riganas et al.'s [10] research.

3.5.2 Peak Work

Table 6

Author	Group	Peak work (W) bef	Peak work (W) after	In between groups	Within groups
Romer et al. [12]	I	294 ± 8 (20km) 271 ± 8 (40km)	305 ± 9 (20km) 280 ± 9 (40km)	P<0.05 (20km) P<0.01 (40km)	
	C	308 ± 13 (20km) 284 ± 13 (40km)	307 ± 12 (20km) 284 ± 12 (40 km)		
Sonetti et al. [15]	I	372 ± 43	391 ± 41	P>0.05	P<0.05
	P	396 ± 36	413 ± 48		P<0.05

I: Intervention P:Placebo C:Control

Romer et al. [12] as well as Sonetti et al. [15] looked at possible differences in peak work prior and post intervention (Table 6).

Sonetti et al. [15] noted the peak work rate subjects achieved during the incremental VO2max test. Romer et al. [12] set the cycle ergometer pedal rate dependent during the 20km and 40km trials with 95 revolutions per minute (rpm) and calculated the peak wattage afterwards.

While Romer et al. [12] found significant in between changes between intervention and control group during 20km trial ($P<0.05$) and 40km trial ($P<0.01$) Sonetti et al. [15] did not find any significant changes in between the groups; both intervention and control group increased peak work dramatically by 19 Watts in the intervention and 17 Watts in the placebo group with both p-values greater than 0.05 within the groups.

3.5.3 VO2

VO2 measurements were done by Romer et al. [12] across all workloads during maximal incremental exercise testings delivering results from 50% until 100% of maximal external power (in this wattage). During the course of the exercise no significant changes were found postintervention compared to preintervention at any stage.

Williams et al. [17] analysed VO2 during endurance exercise testing which included running on a treadmill until volitional fatigue. Measurements were done at a steady state and at the end of the run. No significant changes within or in between groups could be found.

3.5.4 Heart Rate

Williams et al. [17] and Romer et al. [12] measured heart rate at the same time during their exercise testings (endurance exercise testing [17] and maximal incremental exercise testing [12]) as the previous mentioned VO2. Williams et al. [17] did not find any differences during steady state and at the end of the test after the intervention. Romer et al. [12] also did not find any significant changes during the increasing workload.

Sonetti et al. [15] examined the heart rate during the course of the incremental VO2max testing. No significant alterations could be detected over the period of the time tested. Inbar et al. [4] obtained heart rate measurements every 20 seconds during exercise capacity testings. The mean of the peak heart rates of all subjects was calculated and looked at pre- and postintervention. Significance within groups could not be detected. No report is done on significance in between groups changes.

3.5.5 Subjective Measurements (Dyspnea)

During maximal incremental exercise testing Romer et al. [12] recorded personal ratings of respiratory and peripheral exertion. Athletes were asked at the last 30 seconds point of each submaximal exercise stage before power was increased by 35 Wattage (every three minutes). Results showed significant differences in between groups at 60 and 80-100% of the maximal wattage in respiratory effort and during 50-90 % of maximal wattage in peripheral effort in only the intervention group.

Sonetti et al. [15] documented dyspnea ratings during a fixed work rate endurance test asking ratings every 0.8 km. No significant changes could be found in either group except after 18 minutes the placebo group showed significant improvement in subjective dyspnea sensation. No interaction effect could be found.

Williams et al. [17] acquired perceived dyspnea ratings at five minute intervals in the course of the endurance exercise testing. No significant alterations could be found.

Assessment of dyspnea was done during the 2000m all-out effort testing in Riganas et al.'s [10] research. Ratings were done every 500m. No significant changes were found in the intervention as well as control group although a tendency towards improvement could be seen which did not lead to a significant interaction effect.

3.6 Best Evidence Synthesis

According to the NHMRC Evidence Hierarchy all of the above mentioned outcomes are of Level I evidence. All studies are Randomized Controlled Trials with one exception being a Cohort Study.

4. Discussion

4.1 Purpose

The purpose of this study was to find out if Inspiratory Muscle Training is a useful tool to training in endurance athletes by improving physical performance indicators.

Since there have been contrary opinions on the effectiveness of Inspiratory Muscle Training in athletes, this review looked systematically at Randomized Controlled Trials and Cohort Studies that investigated exercise tolerance in runners, swimmers, cyclists and rowers.

4.2 Outcomes

Five studies in total were found that looked at performance indicators including VO2max [4,10,15,17], VO2 [13,18], heart rate [4,12,15,17], maximal work [12,15] and subjective dyspnea sensation [10,12,15,17]. Inspiratory Muscle Training showed no influence on VO2max, VO2 and heart rate [4,10,12,15,17] whereas peak work showed inconclusive findings [10,12,15]. Inconclusive findings were also found for subjective dyspnea sensation [10,12,15,17]. While Romer et al. [12] discovered significant improvement in the intervention group during 60% and 80-100% maximal exercise Sonetti et al., Williams et al. as well as Riganas et al. [10,15,17] did not find any differences whatsoever. These outcomes will be discussed in the following paragraphs.

4.3 VO2 & VO2max

While Williams et al. [17] looked at both VO2 as well as VO2max, the other four studies [4,10,12,15,17] only looked at one of the two outcomes.

An increase in VO2max would imply an increased exercise tolerance since VO2max is known to be a standard of assessing cardiorespiratory level of fitness [7].

Williams et al. [17] as well as the other three studies [4,10,15] indicate no significant increases within intervention and placebo or control group. Inbar et al. [6] and Riganas et al. [10] did not find any interaction effect in between the groups meaning no significant alterations could be seen for the intervention group compared to their control groups.

Sonetti et al. [15] did not report any in between group measurements but looking at the VO2max outcomes before and after it stands out that while the placebo group actually experienced a decrease in the mean value of 0.18% the intervention group increased their VO2max by 2.72% while the other three trials showed no difference at all.

A possible explanation might lie in the training protocol. While Sonetti et al. [15] not only implemented strength training with the POWERbreathe device, they also made use of hyperpnea training for 30 minutes. Furthermore POWERbreathe training was done until task failure. On the other hand Williams et al. [17], Inbar et al. [4] and Riganas et al. [10] had fixed times and/or sets which could mean that the participating athletes might not have been training to their maximum effort. Nevertheless statistical significance of VO2max improvement could not be proven since all four researches indicate towards intervention having no significant effect on VO2max.

This can be further investigated by looking at VO2 measurements that were covered in two articles [12,17]. Both studies implicate submaximal VO2 has not been significantly decreased during any workload. However even though Romer et al. [12] were not able to identify a significant difference in change in between intervention and control group it is worth mentioning average VO2 slightly decreased throughout all workloads in the intervention group indicating an improvement in VO2 capacity which in turn would lead to increased exercise capacity since a growing exercise intensity corresponds with increasing VO2 [7]. Furthermore it could indicate an improvement in mechanical efficiency of working muscles since less oxygen is needed for the same amount of effort [8]. This would be a strong indicator for increased exercise tolerance but as mentioned it is not statistically significant.

While Romer et al. [12] did measurements during maximal incremental exercise in cyclists from 40% to 100% of maximal wattage, Williams et al. [17] only measured VO2 in runners during steady state and after testing. At no stage of either tests was VO2 significantly decreased. The same can be said for in between group comparisons. Since Williams et al. [17] is a cohort study no comparisons could be done.

4.4 Heart Rate

None of the four studies [4,12,15,17] indicated an improvement in between or within groups in heart rate measurements. This result is not surprising considering heart rate measurements were done during maximal exercise performance testings. Heart rate will obviously reach a similar level as before because the objective of the test is the *maximal* work which will reflect in a peaked heart rate. This means in this case it is rather questionable to look at the heart rate as a reliable aid in finding out whether Inspiratory Muscle Training can be used to improve exercise performance.

4.5 Peak Work

Inconclusive findings were encountered by analysing data of peak work and subjective ratings. Romer et al. [12] detected significant improvements in between groups during 20km and 40km time trials in maximal power with p-values below 0.05 with 20km and below 0.01 during 40km respectively. These developments could not be reflected in Sonetti et al.'s [15] research. Not only did the intervention group advance but also the placebo group showed significant progress in peak work during the incremental VO2max test, which led to no significant differences in between both groups. Training setup is very similar in both studies. Both look at subjects who are male only and cyclists. Both make use of the POWERbreathe as a device for Inspiratory Muscle Training and set it up at 50% of the maximal inspiratory pressure. Only Sonetti et al. [15] make use of another form of intervention for Inspiratory Muscle Training namely hyperpnea training. Romer et al. [12] implemented more training in total with training twice a day for six weeks while Sonetti et al. [15] only trained five times per week for five weeks. Altogether that does not explain the difference in outcomes though. A possible explanation could be that while Romer et al. [12] used a fixed distance for the measurements, Sonetti et al. [15] measured the peak work during the maximal testing procedure. During maximal testing every minute the wattage increased by 17W until cadence was less than 60rpm, that was when maximum was reached and the athlete can go no further; this is for both intervention and placebo grouped cyclists. Even though the time trialled test still requires as much effort as possible to finish as quickly as possible, the setup here is different and cyclists most likely do not reach their maximal capacity. Cyclists chose their pedalling rate voluntarily and wattage was calculated beforehand and not changed during the test.

Furthermore Sonetti et al. [15] encouraged their subjects during testing while Romer et al. [12] did not whatsoever. This can have an impact on their performance since verbal encouragement can enhance physical performance [1].

Altogether this might have had an effect on the outcomes in Sonetti et al.'s [15] maximal power measurements and might be the reason for the placebo group improving along with the intervention group.

4.6 Subjective Dyspnea Ratings

As well as maximal work, subjective ratings show inconclusive findings. Romer et al. [12] indicate significant changes in between groups in ratings of perceived exertion in respiratory effort at 60% and 80%-100% and in peripheral effort at 50%-90%. Both Sonetti et al. [15] as well as Riganas et al. [10] showed no significant changes within or in between groups. However, Riganas et al. [10] saw a tendency towards improvement even though it did not reach a significant effect in comparison with both groups. Williams et al. [17] also could not record any significant improvements within the intervention group.

The improved perceived exertion ratings go along with the increase in maximal power in Romer et al.'s [12] research since a subjective decrease in fatigue can enhance exercise tolerance. Since all four studies [10,12,15,17] recorded subjective measurements in different tests and during different times it is hard to compare the ratings with one another and come to a uniform conclusion. While Romer et al. [12] documented subjective ratings during the maximal incremental exercise testing, Riganas et al. [10] recorded ratings during a 2000m all-out effort testing. Sonetti et al. [15] as well as Williams et al. [17] noted dyspnea levels during endurance testings.

Both Romer et al. and Riganas et al. [10,12] mark subjective ratings during a high intensity work performance and both show improvements in perceived subjective ratings even though Riganas et al. [10] did not reach significant interaction levels, while both Sonetti et al. [15] and Williams et al. [17] did recordings of subjective ratings during endurance testings. This makes one wonder if Inspiratory Muscle Training could actually decrease subjective efforts in high intensity exercise while it does not affect low intensity exercise perceptions.

4.7 Functional Benefits?

Inspiratory Muscle Training did not indicate to be a useful add-on with training in endurance athletes. However functional benefits were not looked at yet specifically.

VO2max, submaximal VO2 as well as heart rate, maximum work and dyspnea ratings are all *indicators* for exercise tolerance. In a real life situation when endurance athletes compete in tournaments, it is about finishing the race as fast as possible keeping the endurance throughout, which is not looked at with these measures.

A time trial would actually give the functional component and could give further conclusions if Inspiratory Muscle Training is a good tool to improve physical performance [10,12,15]. If time during a race could be reduced significantly, it would be the most important factor for an athlete to decide whether to make use of Inspiratory Muscle Training additionally with training.

4.8 Strong Points & Limitations

Strong points of this review were definitely the exclusion of all articles that were not Randomized Controlled Trials or Cohort Studies. Even though a Cohort Study is not as strongly evident as a Randomized Controlled Trial since there is no randomization or blinding which could influence outcomes, it still includes an experimental design, which this review was focusing on.

Another strong point was that none of the included articles was of bad quality. Besides one, all articles showed a high score in the quality assessment, which makes outcomes more reliable.

Even though all trials implemented Inspiratory Muscle Training of some kind, no criteria were set beforehand on what device should be used or what focus the training was set on. This way, two different devices (POWERbreathe and Threshold Trainer) were used in the articles with one article adding hyperpnea training as a second measure. One article did not even name the training device used. This could have had a possible effect on outcomes in this research. Another point worth mentioning is that not all key outcomes looked at in this study were covered by all articles. While some outcomes were included in four articles, peak work and VO2 were only part of two. This makes the review on those results less reliable especially since one article was only of acceptable quality [17].

Furthermore group sizes within the studies were rather small ranging from seven to eleven participants in all five studies.

Functional outcomes (time trial) were not covered in this research, which could have put a different light on the results and the conclusion.

4.9 Recommendations

Future research needs to be done in order to be able to identify if Inspiratory Muscle Training can improve exercise capacity in endurance athletes since controversy is still present. The study design should be a Randomized Controlled Trial that includes three groups: one group training with the POWERbreathe device, the second one training with the Threshold Trainer and one placebo group training with a sham device in order to rule out any possible differences in between those two devices. Group sizes should possibly be bigger in order to make outcomes more reliable. Lastly functional measurements like time trials should definitely be a part of the study since this is what athletes will be interested in and what will help them during competitions.

5. Conclusion

None of the five outcome measures, VO2max, VO2, heart rate, peak work or subjective ratings, could be specifically named as being positively stimulated by specific Inspiratory Muscle Training for certain.

With a evidence level of I, VO2max and submaximal VO2 as well as heart rate did not show significant differences in changes in between and within groups in any of the studies.

Peak work and subjective ratings however showed inconclusive findings.

Further research is needed to establish the exact effects Inspiratory Muscle Training has got on exercise tolerance in endurance athletes.

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Appendices

Appendix 1

	SUBJECTS					INTERVENTION				
Author	Group	No	Gender	Age (yo)	Exercise	IMT	Setting (% of Max Inspiratory Pressure)	Repetitions	Frequency	Duration
Romer et al	I	8	♂	29.5 ± 3.3	cyclists	POWERbreathe	50	30	2x/daily	6 wks
	P	8		30.3 ± 2.6			15 (slow protracted breaths)	60	1x/daily	
Sonetti et al	I	9	♂	24.2 ± 4.9	cyclists	1. POWERbreathe 2. Hyperpnea Training	1. 50 2. dynamic respiratory muscle work with all effort increasing depth of breathing every time	1. until task failure 2. 30 mins	5x/week	5 wks
	P	8				Placebo breathing device	normal breathing	30 mins		
Williams et al	I	7	5 ♂, 2 ♀	20.9 ± 1.2	runners	Threshold Trainer	50 progressed 5 each week	4-5 mins 5-7 sets 1-2 mins rest	4-5x/week	4 wks
Inbar et al	I	10		28.9 ± 8.9	track (runners)	Threshold Trainer	1st week: 30, increased every session by 5 until end of week 4, week 5 on 80	30 mins	6x/week	10 wks
	C	10					0			
Riganas et al	I	11	12 ♂, 7 ♀	21.7 ± 5.4	rowers		30 increasing 5 each exercise up to 80 continuing for 4 weeks, breathing frequency self selected pace	30 mins (5-7 sets of 4-5 mins)	5x/week	6 wks
	C	8		19.8 ± 1.5		no intervention				

	OUTCOMES						
Author	**VO2max bef**	**VO2max after**	**VO2: p-value**	**HR: p-value**	**Peak work bef**	**Peak work after**	**Subjective: p-value**
Romer et al			P>0.05	P>0.05	294 ± 8 (20km) 271 ± 8 (40km)	305 ± 9 (20km) 280 ± 9 (40km)	
			P>0.05	P>0.05	308 ± 13 (20km) 284 ± 13 (40km)	307 ± 12 (20km) 284 ± 12 (40 km)	
			No significant changes in between groups	No significant changes in between groups	Significant changes in between groups for both 20km and 40km		Significant changes in between groups (80-100%Wmax)
Sonetti et al	55.0 ± 5.0	56.5 ± 7.3		P>0.05	372 ± 43	391 ± 41*	P>0.05
	54.2 ± 2.5	54.1 ± 4.0		P>0.05	396 ± 36	413 ± 48*	P>0.05
				No significant changes in between groups	No significant changes in between groups		No significant changes in between groups
Williams et al	59.9 ± 11.7	~ 60 ± 10	P>0.05	P>0.05			P>0.05
Inbar et al	58.0 ± 4.6	58.1 ± 5.4		P>0.05			
	61.2 ± 4.7	59.7 ± 7.1		P>0.05			
	No significant changes in between groups						
Riganas et al	~ 52.0 ± 6.0	~ 52.0 ± 6.0					P>0.05
	~ 51.5 ± 6.3	~ 52.0 ± 8.0					P>0.05
	No significant changes in between groups						No significant changes in between groups

*P<0.05, **P<0.01

Appendix 2

PEDro scale: Effects of inspiratory muscle training on time-trial performance in trained cyclists

1. eligibility criteria were specified no _ yes x where: method: subjects

2. subjects were randomly allocated to groups (in a crossover study, subjects

were randomly allocated an order in which treatments were received) no _ yes x where: method: general design

3. allocation was concealed no x yes _ where:

4. the groups were similar at baseline regarding the most important prognostic

indicators no _ yes x where: table 1

5. there was blinding of all subjects no _ yes x where: method: general design

6. there was blinding of all therapists who administered the therapy no x yes _ where:

7. there was blinding of all assessors who measured at least one key outcome no x yes _ where:

8. measures of at least one key outcome were obtained from more than 85%

of the subjects initially allocated to groups no _ yes x where: table 1-3

9. all subjects for whom outcome measures were available received the

treatment or control condition as allocated or, where this was not the case,

data for at least one key outcome was analysed by "intention to treat" no _ yes x where: results: 1st paragraph

10. the results of between-group statistical comparisons are reported for at least one

key outcome no _ yes x where: table 3-4

11. the study provides both point measures and measures of variability for at

least one key outcome no _ yes x where: results

8/11

PEDro scale: Effects of respiratory muscle training versus placebo on endurance exercise performance

1. eligibility criteria were specified no _ yes x where: methods: subjects

2. subjects were randomly allocated to groups (in a crossover study, subjects

were randomly allocated an order in which treatments were received) no _ yes x where: methods: subjects

3. allocation was concealed no x yes _where:

4. the groups were similar at baseline regarding the most important prognostic

indicators no _ yes x where: methods: paragraph 2.2, 2.3, 2.4, 2.5, 2.6

5. there was blinding of all subjects no _ yes x where: methods: paragraph 2.7

6. there was blinding of all therapists who administered the therapy no x yes _ where:

7. there was blinding of all assessors who measured at least one key outcome no x yes _ where:

8. measures of at least one key outcome were obtained from more than 85%

of the subjects initially allocated to groups no _ yes x where: table 1-3, figure 3, 4, 5

9. all subjects for whom outcome measures were available received the

treatment or control condition as allocated or, where this was not the case,

data for at least one key outcome was analysed by “intention to treat” no _ yes x where: methods: paragraph 2.8

10. the results of between-group statistical comparisons are reported for at least one

key outcome no _ yes x where: table 2, 3, figure 1

11. the study provides both point measures and measures of variability for at

least one key outcome no _ yes x where: figure 4

9/11

PEDro scale: Specific inspiratory muscle training in well-trained endurance athletes

1. eligibility criteria were specified no _ yes x where: methods: subjects

2. subjects were randomly allocated to groups (in a crossover study, subjects

were randomly allocated an order in which treatments were received) no _ yes x where: methods: study design

3. allocation was concealed no x yes _ where:

4. the groups were similar at baseline regarding the most important prognostic

indicators no _ yes x where: table 1, 2

5. there was blinding of all subjects no _ yes x where: methods: respiratory training protocol

6. there was blinding of all therapists who administered the therapy no x yes _ where:

7. there was blinding of all assessors who measured at least one key outcome no x yes _ where:

8. measures of at least one key outcome were obtained from more than 85%

of the subjects initially allocated to groups no _ yes x where: results

9. all subjects for whom outcome measures were available received the

treatment or control condition as allocated or, where this was not the case,

data for at least one key outcome was analysed by “intention to treat” no _ yes x where: respiratory training protocol

10. the results of between-group statistical comparisons are reported for at least one

key outcome no _ yes x where: table 1,2

11. the study provides both point measures and measures of variability for at

least one key outcome no _ yes x where: figure 1

8/11

PEDro scale: Specific inspiratory muscle training does not improve performance or VO2max levels in well trained rowers

1. eligibility criteria were specified no _ yes x where: materials and methods: subjects

2. subjects were randomly allocated to groups (in a crossover study, subjects

were randomly allocated an order in which treatments were received) no _ yes x where: materials and method: subjects

3. allocation was concealed no x yes _ where:

4. the groups were similar at baseline regarding the most important prognostic

indicators no _ yes x where: table 2, 3, figure 1-4

5. there was blinding of all subjects no x yes _ where:

6. there was blinding of all therapists who administered the therapy no x yes _ where:

7. there was blinding of all assessors who measured at least one key outcome no x yes _ where:

8. measures of at least one key outcome were obtained from more than 85%

of the subjects initially allocated to groups no _ yes x where: table 1-3

9. all subjects for whom outcome measures were available received the

treatment or control condition as allocated or, where this was not the case,

data for at least one key outcome was analysed by "intention to treat" no _ yes x where: materials and method: inspiratory muscle training protocol

10. the results of between-group statistical comparisons are reported for at least one

key outcome no _ yes x where: table 2

11. the study provides both point measures and measures of variability for at

least one key outcome no _ yes x where: figure 1-3

7/11

PEDro scale: The inspiratory muscle training in elite rowers

1. eligibility criteria were specified no _ yes x where: materials and methods: the subjects

2. subjects were randomly allocated to groups (in a crossover study, subjects

were randomly allocated an order in which treatments were received) no _ yes x where: materials and methods: the subjects

3. allocation was concealed no x yes _ where:

4. the groups were similar at baseline regarding the most important prognostic

indicators no _ yes x where: table 1, 2

5. there was blinding of all subjects no x yes _ where:

6. there was blinding of all therapists who administered the therapy no x yes _ where:

7. there was blinding of all assessors who measured at least one key outcome no x yes _ where:

8. measures of at least one key outcome were obtained from more than 85%

of the subjects initially allocated to groups no _ yes x where: table 1, 2

9. all subjects for whom outcome measures were available received the

treatment or control condition as allocated or, where this was not the case,

data for at least one key outcome was analysed by “intention to treat” no _ yes x where: materials and methods: the inspiratory muscle training

10. the results of between-group statistical comparisons are reported for at least one

key outcome no _ yes x where: table 1, 2

11. the study provides both point measures and measures of variability for at

least one key outcome no _ yes x where: figure 1-4

7/11

SIGN	**Methodology Checklist 3: Cohort studies**

Study identification: Inspiratory muscle training fails to improve endurance capacity in athletes

Guideline topic:	Key Question No:	Reviewer:

Before completing this checklist, consider:

1. Is the paper really a cohort study? If in doubt, check the study design algorithm available from SIGN and make sure you have the correct checklist.
2. Is the paper relevant to key question? Analyse using PICO (Patient or Population Intervention Comparison Outcome). IF NO REJECT (give reason below). IF YES complete the checklist..

Reason for rejection: 1. Paper not relevant to key question ☐ 2. Other reason ☐ (please specify):

Please note that a retrospective study (ie a database or chart study) cannot be rated higher than +.

Section 1: Internal validity

In a well conducted cohort study:		*Does this study do it?*
1.1	The study addresses an appropriate and clearly focused question.	Yes ⊟ No ☐ Can't say ☐
SELECTION OF SUBJECTS		
1.2	The two groups being studied are selected from source populations that are comparable in all respects other than the factor under investigation.	Yes ☐ No ☐ Can't say ☐ Does not apply ⊟
1.3	The study indicates how many of the people asked to take part did so, in each of the groups being studied.	Yes ☐ No ☐ Does not apply ⊟
1.4	The likelihood that some eligible subjects might have the outcome at the time of enrolment is assessed and taken into account in the analysis.	Yes ☐ No ⊟ Can't say ☐ Does not apply ☐
1.5	What percentage of individuals or clusters recruited into each arm of the study dropped out before the study was completed.	0
1.6	Comparison is made between full participants and those lost to follow up, by exposure status.	Yes ☐ No ☐ Can't say ☐ Does not apply ⊟

ASSESSMENT		
1.7	The outcomes are clearly defined.	Yes ⊟ No □ Can't say □
1.8	The assessment of outcome is made blind to exposure status. If the study is retrospective this may not be applicable.	Yes □ No □ Can't say □ Does not apply ⊟
1.9	Where blinding was not possible, there is some recognition that knowledge of exposure status could have influenced the assessment of outcome.	Yes ⊟ No □ Can't say □ □
1.10	The method of assessment of exposure is reliable.	Yes □ No □ Can't say ⊟
1.11	Evidence from other sources is used to demonstrate that the method of outcome assessment is valid and reliable.	Yes ⊟ No □ Can't say □ Does not apply□
1.12	Exposure level or prognostic factor is assessed more than once.	Yes □ No □ Can't say ⊟ Does not apply □
CONFOUNDING		
1.13	The main potential confounders are identified and taken into account in the design and analysis.	Yes ⊟ No □ Can't say □
STATISTICAL ANALYSIS		
1.14	Have confidence intervals been provided?	Yes ⊟ No □
SECTION 2: OVERALL ASSESSMENT OF THE STUDY		
2.1	How well was the study done to minimise the risk of bias or confounding?	High quality (++) □ Acceptable (+) ⊟ Unacceptable – reject 0
2.2	Taking into account clinical considerations, your evaluation of the methodology used, and the statistical power of the study, how strong do you think the association between exposure and outcome is?	
2.3	Are the results of this study directly applicable to the patient group targeted in this guideline?	Yes ⊟ No □

Appendix 3

Fontys Paramedische Hogeschool

B4 Assessment form project plan

Name: Sabrina Krusekamp Student no:

Date: 14-03-2013

Title: Inspiratory muscle training and exercise tolerance in athletes

---

General

- The project plan is according to format	yes /
- Spelling and language are correct	yes /

Problem description and problem definition (introduction)

- The problem description is sufficiently clearly formulated	yes /
- The problem description reflects social and paramedical relevance	yes /
- A concrete and relevant research question (or questions) can be formulated based on the problem definition, including possible sub questions	yes /

Objective

The objective is:

- Sufficiently clearly and concretely formulated	yes /
- Relevant for a selected target group within the (paramedical) professional practice	yes /
- Practically feasible	yes /
- Achievable within the set time	yes /

Project product

The project product:

- Is in line with the problem definition, research question and objective	yes /
- Is usable for the selected target group	yes /
- Is in line with the client's wishes	yes /
- The product requirements are accurately described	yes /

Activities/method

Sufficient insight is given into the type of activities and types of sources for the performance of the research and the realization of the product	yes /

Time schedule

- The time schedule gives a global phasing and time investment for the project as a whole and for the coming weeks an increasingly detailed schedule	yes /
- Important moments are recorded in the table (typographically noticeable) (e.g. contact moments, handing-in moments)	yes /
- The time schedule gives a global task division of the planned activities	yes /

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Estimated costs

Clear insight is given in:

- The costs to be expected concerning money and hours yes /
- The division of these costs (project leader, student, programme) yes /

Literature

- Used and planned literature is specific and mentioned to a sufficient extent yes /
- Relevant and recent literature is referred to yes /
- Literature references, in the text and in the literature list, are made according to the Writer's Guide (Wouters 2012) yes /

Comments: Good project plan Clear rationale and adequate methods Focus on specific parameters of exercise tolerance

All points under B3.1 up to and including B3.8 must be answered with a 'yes' in order to receive a GO for the project. The supervisor discusses with the student which points need adjustment.

GENERAL:	**GO /**

Name assessor: Date + Signature

14-03-2013

Chris Burtin

Steven Onkelinx