Aquatic high-intensity interval training (HIIT) may be similarly effective to land-based HIIT in improving exercise capacity in people with chronic conditions: a systematic review and meta-analysis

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ABSTRACT

Objective To investigate the effect of aquatic high-intensity interval training (AHIT) on exercise capacity in people with chronic conditions.

Design Systematic review and meta-analysis.

Participants Adults (age ≥18 years) with any chronic conditions (long duration, continuing health problems).

Data sources The databases Medline, EMBASE, CINAHL, SPORTSDiscus, PEDro and The Cochrane Library were searched from inception to 11 August 2023.

Eligibility criteria Randomised or non-randomised controlled trials of adults reporting one or more chronic conditions were included, comparing the effect of AHIT with a non-exercising control group, land-based high-intensity interval training (LBHIIT) or aquatic moderate-intensity continuous training (AMICT).

Results Eighteen trials with 868 participants with chronic musculoskeletal, respiratory, cardiovascular, metabolic or neurological conditions were included. Adherence to AHIT was high, ranging from 84% to 100%. There was moderate certainty in evidence according to the Grading of Recommendations Assessment, Development and Evaluation system for a moderate beneficial effect on exercise capacity standardised mean differences (SMD) 0.78 (95% CI 0.48 to 1.08), p<0.00001) of AHIT compared with a non-exercising control group. There was moderate certainty in evidence for no difference of effects on exercise capacity (SMD 0.28 (95% CI −0.04 to 0.60), p=0.08) of AHIT compared with LBHIIT. There was moderate certainty in evidence in small effect on exercise capacity (SMD 0.45 (95% CI 0.10 to 0.80), p=0.01) of AHIT compared with AMICT.

Conclusion There are beneficial effects of AHIT on exercise capacity in people with a range of chronic conditions. AHIT has similar effects on exercise capacity as LBHIIT and may represent an alternative for people unable to perform LBHIIT.

PROSPERO registration number CRD42022289001.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ In general, high-intensity interval training (HIIT) has been considered to have superior health benefits compared with moderate-intensity exercise. This applies to healthy subjects and people with chronic conditions.

⇒ There are many differences in the physiology and biomechanics of exercise in water with conflicting reports on maximal intensity in aquatic exercise. The effectiveness of this exercise needs further comprehensive investigation.

⇒ Some people with chronic conditions have significant barriers to performing land-based high-intensity training (LBHIIT).

WHAT THIS STUDY ADDS

⇒ Aquatic HIIT improves exercise capacity for people with a range of chronic conditions.

⇒ Aquatic HIIT has similar benefits on exercise capacity as LBHIIT for people with chronic conditions.

⇒ Aquatic HIIT may increase adherence to exercise training and should be considered as an exercise option.

INTRODUCTION

The numbers of people managing chronic conditions is growing globally.1 A chronic disease is defined as one having long duration, progressing slowly, and is typically a result of genetics, environment or lifestyle.1 Linked to chronic disease, the broader term chronic condition refers to a continuing health problem that is expensive to manage, with high physical and psychological costs for the individual, caregiver, and health systems.2,3 The impact of chronic conditions on mortality and quality of life is significant.4,6 People with chronic conditions have decreased exercise capacity,7,8 which is associated with further risk of cardiometabolic disease, shortened life expectancy9 and reduced health-related quality of life.10 Exercise is a key component in the management of chronic conditions due to the multitude of benefits to physiological systems, function and quality of
life, as well as being associated with improved disease control.

High-intensity interval training (HIIT) is a form of exercise performed at alternating intensities near an individual’s maximal oxygen uptake (VO2max), with light recovery exercise or no exercise between intervals. It aims to promote increased aerobic capacity and endurance performance by central cardiorespiratory and peripheral changes. Furthermore, HIIT has superior health benefits for vascular function, skeletal muscle metabolism, exercise capacity and other metabolic processes, compared with moderate-intensity continuous training in both healthy and clinical populations. High-intensity interval training is also considered to be more time-efficient. Recent systematic reviews show a greater gain following HIIT in aerobic capacity in healthy middle-aged and older adults than with moderate-intensity continuous training and also in those with hypertension. Some studies including participants with neurological and metabolic conditions report more dropouts and adverse events following the HIIT programme (on land) than with a control exercise programme, which could be a concern when implementing programmes.

The aquatic environment may provide a valuable alternative for HIIT in people with chronic conditions, dealing with barriers related to exercise performance for those with limited movement or pain. In people with limited mobility and weakness, water immersion decreases joint loading and supports movements that may be difficult to perform on land through the effects of buoyancy. When people with pain need to keep weight off a joint after an injury or condition, aquatic exercise programmes may be used effectively to sustain or increase aerobic conditioning. This reduced loading may also make exercise more successful, feasible and enjoyable for people who are unable to train effectively on land, resulting in greater compliance. The aquatic environment may also offer people with limited mobility the ability to train at higher intensities than on land. Additional advantages from cardiovascular conditioning may be obtained from aquatic exercise in populations with sleep or mood disorders, particularly considering mental health-related outcomes. There are many barriers to exercise, including symptoms and function, and common problems among people with chronic conditions are immobility, pain and fatigue. Furthermore, there is a potential for non-adherence due to joint and muscle injury with land-based high-intensity interval training (LBHIIT). There may be a potential in reducing some of these barriers to exercise in the water to facilitate improved longer-term adherence to training programmes.

There may be physiological advantages to aquatic exercise, although evidence related to maximal intensities of aquatic exercise compared with exercise on land is conflicting. Hydrostatic pressure, relative to the depth of immersion, leads to a central shift of blood volume (from legs to abdomen), increasing cardiac preload, stroke volume and cardiac output. In addition, the thermoneutral water temperatures may inhibit sympathetic nervous activity owing to activation of cardiovascular mechanoreceptors. This leads to reduced peripheral arterial tone, improving the efficiency of heart contraction and cardiac function. When exercising at shallow immersion depths, the muscle activity and oxygen uptake can sometimes be greater than when performed at the same pace on land. Despite these valuable effects, some cardiovascular and metabolic responses may be reduced in comparison with similar land-based exercise, related to reduced body weight resistance due to the effect of buoyancy. At equal workload in water, with increased cardiac output, exercise intensity indicators, such as maximal heart rate, anaerobic threshold and maximal oxygen uptake (VO2max), appear lower than on land. However, perceived exertion and respiratory exchange ratio have been reported to be higher in comparison with land-based treadmill running. Potential limitations to aquatic high-intensity interval training (AHITT) may also be connected to difficulties in isolating and controlling movement and overcoming drag forces, as maximal speeds of movement are limited in water compared with LBHIIT for activities such as walking. This may limit the opportunity for both resistance and intensity of cardiovascular exercise, although this is multifactorial and unclear. As there are conflicting benefits and limitations of aquatic exercise, a number of variables that may influence maximal intensity should be considered when performing AHITT. There has also been conflicting evidence in the past about the safety for people with cardiovascular conditions, but more contemporary research documents aquatic exercise as well tolerated.

Aquatic high-intensity interval training has been found to be effective in improving exercise capacity in comparison with a non-exercising control group in three systematic reviews. All reviews combined studies of both healthy participants and participants with chronic conditions. Only four studies using direct measures of exercise capacity as an outcome have been identified in these reviews, including participants with chronic conditions—that is, dyslipidaemia, mild knee osteoarthritis, obesity with polycystic ovary syndrome and mild hypertension. An evaluation of AHITT on improving exercise capacity for people with a broader range of chronic conditions, compared with LBHIIT or other types of aquatic exercise, is needed.

The aim of this systematic review and meta-analysis was to investigate the effect of AHITT on exercise capacity in people with chronic conditions compared with aquatic moderate-intensity continuous training (AMICT), LBHIIT or a non-exercising control group. The secondary aim of the review was to determine adherence to the exercise protocol.

METHODS
This systematic review has been undertaken and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. The review protocol was registered in the International Prospective Register of Systematic Reviews, registration number CRD42022289001.
Data sources and search strategy for identification of studies

The following electronic databases were searched for relevant studies with help from a research librarian, on 11 August 2023: Medline, EMBASE, CINAHL, SPORTSDiscus, PEDro, The Cochrane Library (Cochrane Database of Systematic Reviews) and Cochrane Central Register of Controlled Trials (CENTRAL). The search strategy included terms of aquatic (water, hydrotherapy, swimming), exercise, fitness, rehabilitation, plyometric, tabata or resistance training and high-intensity interval training. There were no restrictions of language or dates in the search, dates of coverage were all records in the databases up until 11 August 2023. The search strategy of each database is shown in online supplemental file 1.

We screened recently completed and ongoing trials at the International Clinical Trials Registry Platform, ClinicalTrials.gov, Epistemonikos, and Open Science Framework. A Google Scholar search was also undertaken and a citation search in several key papers. In addition, a manual search of reference lists of included articles and reviews was completed.

Eligibility criteria

Design
Randomised and non-randomised clinical trials with a minimum intervention of 6 weeks, which evaluated the effect of AHIIT on exercise capacity, were considered for inclusion. Studies written in English, Norwegian, Swedish or Danish and published as full papers were included.

Participants
The study population was limited to participants aged ≥18 years reporting one or more chronic conditions.

Intervention
For the aquatic exercise to be considered ‘high intensity’, AHIT was defined as exercises in water consisting of repeated bouts of intermittent work performed with a work rate of perceived exertion (RPE) ≥14 (BORG Exertion Scale), or maximal heart rate ≥77% of predicted maximum heart rate, or rate of oxygen uptake (VO₂) >64% of VO₂peak, or maximal capacity, or defined in the title or text as an intervention that is considered high intensity and conducted in intervals or bouts followed by a recovery period. Studies that did not specify how exercise intensity was monitored were excluded. The comparison group might have been control (usual care) or exercise (LBHIIT or another form of aquatic exercise).

Outcomes
The primary outcome of interest was exercise capacity. The following measures were considered relevant: maximal oxygen consumption (VO₂peak/max), 6–12 min walk tests (MWT), shuttle walk tests and submaximal physical fitness tests. Adherence to the exercise protocol and adverse events were also reported as secondary outcomes.

Study selection
One author (HB-N) conducted the database search. Duplicate papers were removed, and three other reviewers (KEH, BBN, LAHK) independently reviewed titles and abstracts of all studies to identify which studies were obtained in full text. Thereafter, full-text screening in two review-pairs independently applied the a priori defined selection criteria using Rayyan, a web tool for systematic reviews. Disagreement about eligibility among the review authors was discussed with all authors to achieve consensus.

Data extraction
One review author (HB-N) extracted the data from the included studies. The extraction was verified by one of the three other reviewers (KEH, BBN, LAHK). Data extracted and recorded included authors, year, country, study design and methods, characteristics of study participants (age, sex, chronic condition), interventions (exercise components, duration, frequency and intensity), outcome measures of interest (postintervention mean and SD or change scores), adherence and any adverse events recorded.

Outcome measures were entered into Review Manager (web and software). Authors were contacted by mail to obtain data that were missing.

Quality assessment
Four authors (HB-N, KEH, BBN, LAHK) independently assessed the risk of bias for the selected outcome (high, low or some concerns), and assessment was made separately for randomisation process, deviations from the intended interventions, missing outcome data, measurement of the outcome and selection of the reported result in each included study using the Cochrane Collaboration risk-of-bias tool (RoB2). Unclear or missing information in the publications were checked by correspondence with authors.

For each outcome/analysis, to evaluate confidence in the cumulative evidence, assessment was made with Grading of Recommendations Assessment, Development, and Evaluation (GRADE). The certainty of evidence was divided into categories: high, moderate, low or very low according to how certain we were that the estimated effect was true. To judge for possible downgrading of the certainty of evidence and strength of recommendations, risk of bias, consistency, directness, precision, and publication bias were used as criteria. Publication bias was assessed only for meta-analysis with ≥10 trials. The power of the test is too low to separate chance from real asymmetry.

Data synthesis and statistical analysis
A narrative synthesis of the findings from the included studies around the type of intervention, type of outcome, population characteristics and intervention context was completed. Pooling of individual studies was performed for particular outcome if there was more than one study. We used a random-effects model, as appropriate, based on analysis of the included studies.

Meta-analyses were conducted using an estimate of the effect of mean post-treatment (VO₂ mL/kg/min or metres walked) values for both interventions and control groups with SD. In one trial where mean change was the only presented result, this was used in addition to SD for both groups. If only confidence intervals (CIs) or SE were presented, we calculated SD (using the Review Manager calculator). We calculated standardised mean differences (SMD) with 95% CIs to assess pooled outcomes of exercise capacity. The interpretation of SMD as an effect size was based on Cohens d (0.2–0.49 is small, 0.5–0.79 is moderate and ≥0.8 is large). Meta-analyses were conducted using Review Manager 5.4.1 software and the Review Manager web. Heterogeneity was tested using the I² test. Where necessary, high causes of heterogeneity were explored using sensitivity analysis. Forest plots were constructed to visualise the results. Publication bias was assessed with graphical methods as funnel plots.

RESULTS

Study selection

Our search results are summarised in the PRISMA flow diagram (figure 1). A total of 15,322 records were identified, of which some studies were excluded studies for the reasons outlined in online supplemental file 2. Forty-one studies were assessed in full text. Eighteen trials were included in the systematic review and 16 were eligible for meta-analysis. One study and parts of another study were not included in the meta-analysis owing to a lack of available outcome data.

Equity, diversity and inclusion statement

Our review included studies with people considered as a marginalised group, with one or more chronic conditions, mostly women. People in lower socioeconomic groups are more likely to have long-term health conditions. The included studies were conducted in South America, Europe, North America, The Middle East and Asia. Our analysis explores the effect of AHIIT on exercise capacity in people who may have barriers to LBHIIT. The findings are considered and presented in the discussion.

Description of the included studies

A total of 868 participants are included in this review. The main characteristics of the included studies are listed in table 1. The studies included 325 participants with musculoskeletal conditions, including chronic low back pain, knee osteoarthritis and fibromyalgia; 188 participants with respiratory conditions, including chronic obstructive pulmonary disease and asthma; 146 participants with cardiovascular conditions, including mild arterial hypertension, and peripheral artery disease; 127 participants with metabolic conditions,
including dyslipidaemia, diabetes type 2, polycystic ovary syndrome and obesity; and 82 participants with neurological conditions, including chronic motor incomplete spinal cord injury, multiple sclerosis and chronic stroke. A total of 74% of the participants were female (n=640). In six of the studies participants were excluded if they had comorbidities, and in four studies participants’ comorbidities were reported. Comorbidities reported were musculoskeletal (arthritis, osteoporosis, disc protrusion), cardiovascular (mild arterial hypertension, peripheral artery disease, cardiac or other vascular diseases) and metabolic conditions

Table 1: Study design and participants characteristics (n=18)

<table>
<thead>
<tr>
<th>Reference (year), country</th>
<th>Study design and study duration</th>
<th>Sample size and condition</th>
<th>M/F</th>
<th>Age (years)</th>
<th>Outcome of interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andrade et al161 (2017), Brazil</td>
<td>2-arm RCT, 16 weeks</td>
<td>n=54, FM</td>
<td>0/54</td>
<td>AHII: 48±8&lt;br&gt;CG: 47±8</td>
<td>VO2peakp</td>
</tr>
<tr>
<td>Assis et al162 (2006), Brazil</td>
<td>2-arm RCT, 15 weeks</td>
<td>n=60, FM</td>
<td>0/60</td>
<td>DWR+AMICT: 43±11&lt;br&gt;LBHIIT: 42±11</td>
<td>VO2peakp</td>
</tr>
<tr>
<td>Carvahlo et al163 (2020), Brazil</td>
<td>2-arm RCT, 9 weeks</td>
<td>n=54, CLBP</td>
<td>17/37</td>
<td>AMICT+DWR: 47±10&lt;br&gt;AMICT: 46±11</td>
<td>6MWTp</td>
</tr>
<tr>
<td>Chu et al71 (2004), Canada</td>
<td>2-arm RCT, 8 weeks</td>
<td>n=13, Chronic stroke</td>
<td>12/1</td>
<td>AHII: 61.9±9.4&lt;br&gt;CG: 63.4±8.4</td>
<td>VO2maxp</td>
</tr>
<tr>
<td>Costa et al43 (2018), Brazil</td>
<td>2-arm RCT, 12 weeks</td>
<td>n=40, Dyslipidaemia</td>
<td>0/40</td>
<td>AHII: 46.24 (44.65, 47.83)&lt;br&gt;AMICT: 46.77 (44.78, 48.76)</td>
<td>VO2peakp</td>
</tr>
<tr>
<td>Delevatti et al70 (2020), Brazil</td>
<td>3-arm RCT, 15 weeks</td>
<td>n=57, DM2</td>
<td>28/29</td>
<td>AHII: 58±7&lt;br&gt;AMICT-COMBI: 61±7&lt;br&gt;CG: 59±10</td>
<td>VO2peakp</td>
</tr>
<tr>
<td>Emtner et al60 (1998), Sweden</td>
<td>2-arm RCT, 10 weeks</td>
<td>n=32, Asthma</td>
<td>18/14</td>
<td>AHII: 34±8&lt;br&gt;LBHIIT: 38±12</td>
<td>12MWTp</td>
</tr>
<tr>
<td>Felcar et al66 (2018), Brazil</td>
<td>2-arm RCT, 26 weeks</td>
<td>n=70, COPD</td>
<td>23/13</td>
<td>AHII: 69±9&lt;br&gt;LBHIIT: 68±8</td>
<td>VO2peakp</td>
</tr>
<tr>
<td>Gallo-Silva et al67 (2019), Brazil</td>
<td>2-arm RCT, 8 weeks</td>
<td>n=43, COPD</td>
<td>43/0</td>
<td>AHII: 66±10&lt;br&gt;CG: 67±7</td>
<td>6MWTp</td>
</tr>
<tr>
<td>Gorman et al72 (2019), USA</td>
<td>2-arm RCT, 12 weeks</td>
<td>n=37, CMISC</td>
<td>28/9</td>
<td>AHII: 50±10&lt;br&gt;Robot LBHIIT: 45±13</td>
<td>VO2peakp</td>
</tr>
<tr>
<td>Kanitz et al64 (2021), Brazil</td>
<td>2-arm RCT, 12 weeks</td>
<td>n=22, CLBP</td>
<td>9/13</td>
<td>AHII: 35 (23 to 48)&lt;br&gt;AMICT: 41 (31 to 50)</td>
<td>VO2peakp</td>
</tr>
<tr>
<td>Kargarfard et al73 (2018), Iran</td>
<td>2-arm RCT, 8 weeks</td>
<td>n=32, MS</td>
<td>0/32</td>
<td>AHII: 37±9&lt;br&gt;CG: 36±7</td>
<td>6MWTp</td>
</tr>
<tr>
<td>Mohr et al166 (2014), Denmark</td>
<td>3-arm RCT, 15 weeks</td>
<td>n=62, Mild arterial HT</td>
<td>0/62</td>
<td>AHII: 44±9.1&lt;br&gt;AMICT: 46±9.1&lt;br&gt;CG: 45±8.9</td>
<td>Yo-Yo IEp</td>
</tr>
<tr>
<td>Munukka et al164 (2016), Finland</td>
<td>2-arm RCT, 16 weeks</td>
<td>n=87, OA</td>
<td>0/87</td>
<td>AHII: 64±2&lt;br&gt;CG: 64±2</td>
<td>VO2peakp</td>
</tr>
<tr>
<td>Olkoski et al65 (2021), Brazil</td>
<td>2-arm RCT, 9 weeks</td>
<td>n=48, CLBP</td>
<td>0/48</td>
<td>AMICT+DWR: 47±10&lt;br&gt;AMICT: 47±11</td>
<td>Kgfp</td>
</tr>
<tr>
<td>Park et al69 (2019), South Korea</td>
<td>2-arm RCT, 12 weeks</td>
<td>n=84, PAD</td>
<td>0/84</td>
<td>AHII: 70±1&lt;br&gt;CG: 71±8</td>
<td>VO2peakp</td>
</tr>
<tr>
<td>Samadi et al65 (2019), Iran</td>
<td>2-arm RCT, 12 weeks</td>
<td>n=30, PCOS</td>
<td>0/30</td>
<td>20–35</td>
<td>VO2peakp</td>
</tr>
<tr>
<td>Wadell et al68 (2004), Sweden</td>
<td>3-arm controlled and semirandomised trial, 12 weeks</td>
<td>n=43, COPD</td>
<td>16/27</td>
<td>AHII: 65±4&lt;br&gt;LBHIIT: 65±7</td>
<td>VO2peakp</td>
</tr>
</tbody>
</table>

Data are expressed as mean±SD. AHII, aquatic high-intensity interval training; AMICT, aquatic moderate-intensity continuous training; CG, control group; CI, 95% CI; CLBP, chronic low back pain; CMISC, chronic motor incomplete spinal cord injury; COPD, chronic obstructive pulmonary disease; DM, diabetes mellitus type 2; DWR, deep water running; FM, fibromyalgia; HT, hypertension; IE, intermittent endurance; kgf, kilogram force; LBHIIT, land-based high-intensity interval training; MS, multiple sclerosis; MWT, 6–12 min walk test; OA, osteoarthritis; p, primary outcome; PAD, peripheral artery disease; PCOS, polycystic ovary syndrome; RCT, randomised controlled trial; s, secondary outcome.
(obesity, diabetes mellitus, dyslipidaemia, thyroid dysfunction and insulin resistance). 

Water temperature was between 26°C and 33°C in the studies, predominantly with temperatures between 28°C and 32°C. In three trials participants were immersed to the level of siphoid process and in five trials head out of water. In two trials participants were immersed in levels of waist to chest.

### Descriptions of the exercise interventions

The exercise programmes were group-based in 15 studies (85%), individually supervised in two studies (11%), and in one study consisting of deep water running it was not explicitly stated. Characteristics of the interventions used in included studies are summarised in online supplemental file 3.

### Comparison group

A number of trials (39%) evaluated the effect of AHIIT versus a non-intervention control group, four trials (22%) evaluated the effect of AHIIT versus LBHIIT, four trials evaluated AHIIT versus AMICT, and three trials were three armed and evaluated AHIIT versus LBHIIT and control, AHIIT versus aquatic resistance and aerobic combination training and a control group, and AHIIT versus aquatic moderate intensity exercise and a control group. The target training intensity profiles were matched in all LBHIIT and AHIIT studies, and were increased in a similar way for LBHIIT and AHIIT during the exercise programme. Further detailed descriptions are given in online supplemental file 3.

### Outcome

Seven studies (39%) had exercise capacity as primary outcome, 11 as a secondary outcome (61%). Detailed descriptions are given in online supplemental file 3.

### Risk of bias

Risk of bias is shown in figures 2–4. A summary of risk of bias in the 18 included studies is shown in online supplemental figure S4. All results in the trials were judged based on their assignment to the intervention or intention-to-treat effects. Two studies were judged ‘low risk of bias’, most studies with ‘some concerns’ and two studies were judged with ‘high risk of bias’ related to the outcome exercise capacity. Detailed descriptions are presented in online supplemental file 5.

### Effects of aquatic high-intensity interval training on exercise capacity

**AHIIT compared with control group**

Ten randomised controlled trials (RCTs) provided data on exercise capacity for AHIIT versus control group, and the results showed moderate certainty in evidence for a moderate beneficial effect (SMD 0.78 (95% CI 0.48 to 1.08), p<0.00001) (figure 2). There was between-group heterogeneity (I²) of 52%, p=0.03. See online supplemental table S6 for details of the GRADE.

**AHIIT compared with LBHIIT**

Four RCTs provided data for AHIIT versus LBHIIT, and there was moderate certainty in evidence for no differences of effects of exercise (SMD 0.28 (95% CI −0.04 to 0.60), p=0.08) (figure 3). There was no between-group heterogeneity (I²=0%).

**AHIIT compared with AMICT**

Four RCTs provided data for AHIIT versus AMICT, and there was moderate certainty in evidence for small beneficial effect for AHIIT (SMD 0.45 (95% CI 0.10 to 0.80), p=0.01) (figure 4). The between-group heterogeneity was negligible (I²=0%).

### Certainty of evidence

The certainty of evidence (GRADE) is presented in figures 2–4 and online supplemental file S6. The certainty of evidence is included in the analyses of effect of AHIIT versus control, AHIIT versus LBHIIT, and AHIIT versus AMICT on exercise capacity and was rated moderate in each case. In the AHIIT vs control analyses the certainty was downgraded to moderate related to inconsistency. There were some concerns related to substantial heterogeneity (I² 52%), high X², and significant p value (0.03). The effect sizes varied and there was limited overlap of confidence intervals.

In the AHIIT versus LBHIIT analyses the certainty was downgraded to moderate related to imprecision in the estimate of the effect. The total number of participants (n=156) was a concern, and the effect size crossed the line of no effect. In the AHIIT vs AMICT the certainty was downgraded to moderate related to imprecision in the estimate of the effect. The total number of participants was a concern (n=131).}

### Studies excluded from the meta-analyses

Two studies were not included in the meta-analysis owing to a lack of available outcome data. Emtner et al reported an increase in 12 MWT of 101 m in the AHIIT group and 90 m in the LBHIIT group. Mohr et al reported an improvement of 45% in the AMICT group on the Yo-Yo IE1 test and 58% in the AHIIT group.

### Adherence

Twelve trials included a report of adherence to the exercise (67%), ranging from 84% to 100%. In the LBHIIT group adherence ranged from 85% to 100%, and from 84% to 100% in the AHIIT group. One trial reported similar adherence in both LBHIIT and AHIIT groups, with participants completing two-thirds of all sessions.

### Adverse events

Four trials reported adverse events. One trial reported three asthmatic attacks, although it was unclear if these were in the LBHIIT or AHIIT group.
<table>
<thead>
<tr>
<th>Author, year, condition</th>
<th>Defined intensity</th>
<th>Times per week</th>
<th>Number of weeks (total sessions)</th>
<th>Time per session (min)</th>
<th>Descriptions of AHIT</th>
<th>Descriptions of comparison groups</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Musculoskeletal conditions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Andrade et al. (2017) (FM)</td>
<td>VAT</td>
<td>2</td>
<td>16 (32)</td>
<td>45</td>
<td>Lower limb exercises sitting on floats (80% VAT HR) (level 1), jumping on a trampoline (110% VAT HR) (level 2), exercises in aquatic cycle with resistance adjustment (100% VAT HR) (level 3). Resistance exercise of upper limbs using floats</td>
<td>Control group did not receive any intervention.</td>
</tr>
<tr>
<td>Assis et al. (2006) (FM)</td>
<td>HR&lt;sub&gt;AT&lt;/sub&gt;</td>
<td>3</td>
<td>15</td>
<td>60</td>
<td>DWR: running in place, upper limbs alternating shoulder flexion-extension movements, hands held tightly clenched, lower limbs in a bicycling action</td>
<td>LBHIIT: Aerobic training according to the desired intensity for 40 min. Walking or jogging. Heart rate (HR) was readjusted after week eight based on the second test.</td>
</tr>
<tr>
<td>Carvalho et al. (2020) (CLBP)</td>
<td>RPE</td>
<td>2</td>
<td>9 (18)</td>
<td>60 (40+20)</td>
<td>DWR, week 1–2: 20 min, RPE 11, week 3–9: 20 min, RPE 15. Walking forwards/sideways/backwards, Lumbar spine stabilisation, dynamic exercises, transversal rotations, method Bad Ragaz Ring. Lumbar and axial tractions</td>
<td>AMICT: Aquatic exercise 40 min without DWR. Sets: 1×60 s, 1×30 s, 2×30 s; Lumbar spine stabilisation, dynamic exercises, transversal rotations, method Bad Ragaz, Lumbar and axial tractions.</td>
</tr>
<tr>
<td>Kanitz et al. (2021) (CLBP)</td>
<td>HR&lt;sub&gt;VT2&lt;/sub&gt;</td>
<td>2</td>
<td>12</td>
<td>45</td>
<td>DWR: week 1–4: 7 x (3 min 95% HR&lt;sub&gt;VT2&lt;/sub&gt; + 2 min &lt; 85% HR&lt;sub&gt;VT2&lt;/sub&gt;) week 5–8: 7 x (4 min 100% HR&lt;sub&gt;VT2&lt;/sub&gt; + 1 min &lt; 85% HR&lt;sub&gt;VT2&lt;/sub&gt;) week 9–12: 7 x (3 min 100% HR&lt;sub&gt;VT2&lt;/sub&gt; + 1 min 105% HR&lt;sub&gt;VT2&lt;/sub&gt; + 2 min &lt; 85% HR&lt;sub&gt;VT2&lt;/sub&gt;)</td>
<td>AMICT: DWR: week 1–4: 7 x (3 min 85% HR&lt;sub&gt;VT2&lt;/sub&gt; + 2 min &lt; 85% HR&lt;sub&gt;VT2&lt;/sub&gt;) week 5–8: 7 x (4 min 90% HR&lt;sub&gt;VT2&lt;/sub&gt; + 1 min &lt; 85% HR&lt;sub&gt;VT2&lt;/sub&gt;) week 9–12: 7 x (4 min 95% HR&lt;sub&gt;VT2&lt;/sub&gt; + 1 min &lt; 85% HR&lt;sub&gt;VT2&lt;/sub&gt;)</td>
</tr>
<tr>
<td>Munukka et al. (2016) (OA)</td>
<td>As ‘hard and fast as possible’</td>
<td>3</td>
<td>16</td>
<td>60 (48)</td>
<td>Exercises progressed from barefoot, small fins to large resistance boots (no contact with pool walls or bottom): 2 set x 30–3 set x 30–45 reps, with rest period 30–45 s. From week 3 to 16: Borg &gt;15</td>
<td>Control group did not receive any intervention.</td>
</tr>
<tr>
<td>Olkoski et al. (2021) (CLBP)</td>
<td>80% of HR, 2 RPE 15</td>
<td>50 (AMICT)</td>
<td></td>
<td></td>
<td>DWR: week 1–2: 50% hour work, RPE 11 (20 min), week 3–9: 80% of HR work, RPE 15. Walking forwards/sideways/backwards, Lumbar spine stabilisation, dynamic exercises, transversal rotations, method Bad Ragaz Ring. Lumbar and axial tractions</td>
<td>AMICT: 1–2 reps, 30–60 s, walking different directions, dynamic exercises hip joint muscles: walking forwards/sideways/backwards, Lumbar spine stabilisation, dynamic exercises, transversal rotations, method Bad Ragaz Ring. Lumbar and axial tractions.</td>
</tr>
<tr>
<td><strong>Metabolic conditions</strong></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Costa et al. (2018) (dyslipidaemia)</td>
<td>RPE 9–15</td>
<td>2</td>
<td>12 (24)</td>
<td>45</td>
<td>Water aerobics exercises for upper and lower limbs (abduction/adduction, flexion/extension) including flexion of trunk, interval method was adopted throughout the training period</td>
<td>Control group did not receive any intervention.</td>
</tr>
<tr>
<td>Delevatti et al. (2020) (DM2)</td>
<td>50 min 85–90% HR&lt;sub&gt;AT&lt;/sub&gt;</td>
<td>3</td>
<td>15</td>
<td>56</td>
<td>Lower limb exercises: stationary running, front kick, cross-country skiing, backward stationary running, and hip extension, accompanied with upper limbs movements. 2 min of lower limb exercise, combined with two upper limb exercises (1 min each)</td>
<td>Control group: stretching and relaxation sessions. COMBI group (NIA): resistance: RPE 19+greatest possible velocity of motion and resistance. Intervals, sets of 15–30 s.</td>
</tr>
</tbody>
</table>

Continued
<table>
<thead>
<tr>
<th>Author, year, condition</th>
<th>Defined intensity</th>
<th>AHIT, + AMICT + LBHIIT characteristics</th>
<th>Time per session (min)</th>
<th>Descriptions of AHIT</th>
<th>Descriptions of comparison groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samadi et al (2019) (PCOS)</td>
<td>80–95% hour ‘all-out’ max work intervals</td>
<td></td>
<td>30</td>
<td>Quick movements of body (20 min): 4 x 4 min bouts, 8 rounds of 20 s intervals. 1 min of rest between intervals (75% HRmax)</td>
<td>Control group did not receive any intervention (only Metformin)</td>
</tr>
<tr>
<td>Felcar et al (2018) (COPD)</td>
<td>85% of baseline max workload, and 110% of baseline 6MWT velocity, RPE 4–6</td>
<td>3</td>
<td>12</td>
<td>Both groups: endurance training (cycling and walking), strength training for lower (quadriceps) and upper (biceps and triceps) (3 sets x eight reps) limbs and stretching, eight educational sessions</td>
<td>LBHIIT: Both groups: endurance training (cycling and walking), strength training for lower (quadriceps) and upper (biceps and triceps) (3 sets x eight reps) limbs and stretching, 8 educational sessions.</td>
</tr>
<tr>
<td>Gallo-Silva et al (2019) (COPD)</td>
<td>RPE 6</td>
<td></td>
<td>60</td>
<td>Moderate intensity to high intensity, aim RPE 4–6 in six steps, 1 min break between. Duration: 20 min, progression to 40 min. Main exercise: aerobic exercises for the trunk, upper limbs and lower limbs involving the hips, feet, ankles, hands/wrists and shoulders</td>
<td>Control group did not receive any intervention.</td>
</tr>
<tr>
<td>Wadell et al (2004) (COPD)</td>
<td>80–100% HRpeak RPE 15</td>
<td>3</td>
<td>12</td>
<td>Endurance (3 x 4 min) + 3 min strength (legs, arms, torso), repetitive large-muscle exercises intending to increase the load on the cardiovascular system and increase heart rate</td>
<td>LBHIIT: Both land and water training programme were designed to have the same intensity profile. Control group: no training intervention.</td>
</tr>
<tr>
<td>Neurological conditions</td>
<td></td>
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<tr>
<td>Chu et al (2004) (chronic stroke)</td>
<td>80% HRR5 beats/min</td>
<td>3</td>
<td>8</td>
<td>Moderate to high aerobic activities: shallow water walking, running, side stepping, 30 min</td>
<td>AMICT: Gross+fine motor movements for upper limbs while sitting.</td>
</tr>
<tr>
<td>Gorman et al (2019) (CMISCI)</td>
<td>75% HR, RPE 16–17</td>
<td>Up to 3</td>
<td>12</td>
<td>Cardiorespiratory and strengthening components with rest periods of 1 to 3 min. Hip flex/ext/abd/add, knee flex/ext. Lunge walking/semireclined paddling/kickboard. Step ups, push-ups, push off wall tethered, cycling UE and LE seated/semireclined. Adapted swim strokes. Work at 65–75% intensity level throughout each aquatic exercise sessions</td>
<td>LBHIIT: Lokomat training; 20–45 min. Walking.</td>
</tr>
<tr>
<td>Kargarfard et al (2018) (MS)</td>
<td>75% of HRR</td>
<td>3</td>
<td>8</td>
<td>Walking at different intensities, joint mobility, functional exercises, balance. 10–12 reps of movements in a circuit class format</td>
<td>Control group: no training intervention. Weekly educational sessions for both groups.</td>
</tr>
<tr>
<td>Author, year, condition</td>
<td>Defined intensity</td>
<td>Times per week</td>
<td>Number of weeks (total sessions)</td>
<td>Time per session (min)</td>
<td>Descriptions of AHIT</td>
</tr>
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<tr>
<td>Cardiovascular conditions</td>
<td>Mohr et al. (2014) (HT)</td>
<td>All-out intervals</td>
<td>3</td>
<td>15</td>
<td>-15–25, 60 (AMICT)</td>
</tr>
<tr>
<td></td>
<td>Park et al. (2019) (PAD)</td>
<td>70–85% HRR, RPE 6–8</td>
<td>4</td>
<td>12</td>
<td>60</td>
</tr>
</tbody>
</table>

Bold types indicate comparison intervention.

AHIT, aquatic high-intensity interval training; AMICT, aquatic moderate-intensity continuous training; CLBP, chronic low back pain; CMISC1, chronic motor incomplete spinal cord injury; COPD, chronic obstructive pulmonary disease; DM2, diabetes mellitus type 2; DWR, deep water running; FM, fibromyalgia; HR, heart rate; HRR, heart rate reserve; HT, hypertension; LBHIIT, land-based high-intensity interval training; LE, lower limb; MS, multiple sclerosis; MWT, 6–12 min walk test; NI, no information; NIA, not included in analyses; OA, osteoarthritis; PAD, peripheral artery disease; PCOS, polycystic ovary syndrome; RPE, rate of perceived exertion; UE, upper limb; VAT, ventilatory anaerobic threshold.
A wide range of people with chronic conditions found beneficial effects of AHIIT on exercise capacity, some with multiple conditions. The moderate beneficial effect of AHIIT in comparison with a non-exercising control group supports the findings of previous reviews with smaller numbers of studies including people with chronic conditions. Included in the range of chronic conditions were people with musculoskeletal conditions, respiratory conditions, cardiovascular conditions, metabolic conditions, and neurological conditions. Participants had more than one chronic condition in four of the studies, indicating there may be value for people with multimorbidity.

The population under study in our systematic review are a heterogeneous group and may have a variety of physical disabilities or limiting symptoms. Some participants may have limitations to activities related to joint pain and weakness (eg, musculoskeletal conditions and metabolic conditions), whereas others (eg, those with cardiovascular and respiratory conditions) may have endurance limitations, and reduced strength, or others (eg, those with neurological conditions) may...
have difficulties with walking speed,11 coordination81–83 or fatigue.84 Despite these differences in presenting symptoms and impairments, our findings show that a range of people with chronic conditions may increase their exercise capacity by including HIIT in the aquatic exercise routine.

There may be further potential for AHIIT if greater exercise intensity was performed in studies. According to Ross et al,85 an increase of maximal oxygen consumption ≥3.5 mL/kg/min has been reported as valuable for increasing health outcomes and survival. Only three of the trials in the present review reported an increase in VO2max of ≥3.5 mL/kg/min.45 70 71 However, the minimum clinical important difference will vary across populations, and for some chronic conditions lower values, such as 1.5 mL/kg/min, have been reported as the minimum clinical important difference.86 87 which would allow the results of three more trials to be included in this review.43 44 69

High-intensity interval training in water may deliver greater improvement in exercise capacity than moderate-intensity training but has only been evaluated in a small number of studies. Compared with AMICT, AHIIT was effective in increasing exercise capacity. The trials comparing AHIIT with AMICT mainly included people with musculoskeletal conditions, and one trial with neurological conditions in the analysis. Further studies are needed to confirm this.

The value of AHIIT in reducing injury and adverse events is unclear as few studies report on this in detail, although the adherence rates for people with chronic conditions is promising. People with multiple chronic conditions face significant challenges with treatment, and their preferences for healthcare, together with emphasising treatments that increase quality of life with little harm, are a priority.4 Land-based studies have flagged issues with injury and adverse events following HIIT.21–24 Results from our study show beneficial adherence to AHIIT, ranging from 84% to 100%.43 44 60 62 63 66 68 70–73 Furthermore, the results of this review showed few adverse events. Therefore, AHIIT may be a valuable alternative to increase adherence to exercise programmes. More comprehensive reporting of adverse events in further studies is warranted.

Strength and limitations of the review
A major strength of this review is the comprehensive search strategy in multiple databases. Four authors attempted to identify all relevant studies and contributed to the search in different stages to expand and explore the literature. Another strength is the inclusion of several chronic conditions, with comprehensive details of participants with multimorbidity, and the inclusion of adverse events and adherence outcomes, enabling a greater depth of understanding of AHIIT in a variety of populations.

Limitations of the review include that one of the meta-analyses (AHIIT vs control group) presented moderate to substantial statistical heterogeneity and should be interpreted with caution. There are some methodological concerns related to the included trials that did not report whether the outcome assessor was blinded,44–46 60 61 which might affect results in studies comparing training with a control group.44 61 We did not search for, extract, or analyse, data investigating moderate-intensity exercise in water compared with a control group and therefore have limited insights into these outcomes. In the included trials, exercise intensity was closely monitored and might have contributed to better outcomes. No exploration was carried out of how long improvements in exercise capacity persist in these groups or the impact on function or quality of life in this analysis. In future research, it would be useful to examine the link between exercise capacity and key patient-related outcomes, barriers to HIIT and the ongoing independent commitment to exercise. Few studies included in this review had follow-up
periods after the intervention, and this is an area of interest for the future.

CONCLUSION
This meta-analysis showed beneficial effects of AHIIIT on exercise capacity in people with chronic conditions. AHIIIT may have similar effects on exercise capacity to those of LBHIIT and may be a valuable alternative for people with barriers to performing high-intensity exercise on land. While there may be differences in physiology and biomechanics in water, AHIIIT appears to provide an adequate stimulus for cardiovascular training. Although the beneficial effect of AHIIIT on exercise capacity in chronic conditions is promising, further high-quality research is required.

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Contributors HB-N led the work and had responsibility for the study. HB-N had access to the data, selected the eligible studies from the systematic searches, extracted the data, led the interpretation of the results and drafted the manuscript, and acted as guarantor. KEH, BBN and LAHK participated in the conception and design of the study, selected the eligible studies from the systematic searches, extraction of data and writing the manuscript. SH drafted the manuscript and revised it critically. All authors read and approved the final manuscript for submission.

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