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Technology supported High Intensity Training in chronic non-specific low back pain (the Techno-HIT trial): study protocol of a randomised controlled trial

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ABSTRACT

Chronic low back pain (CLBP) is one of the most common chronic musculoskeletal disorders worldwide. Guidelines recommend exercise therapy (ET) in CLBP management, but more research is needed to investigate specific ET modalities and their underlying mechanisms. The primary goal of this study is to evaluate the short-term and long-term effectiveness of a time-contingent individualised high-intensity training (HIT) protocol on disability compared with a time-contingent moderate-intensity training (MIT) as used in usual care, in persons with severely disabling CLBP. Additionally, the effectiveness on central effects, the added value of prolonged training at home and technology support, and the cost-effectiveness are evaluated. In this randomised controlled trial, CLBP patients will be randomly divided into three groups of 56 participants. Group 1, 'TechnoHIT', receives HIT with technology-support in the home-phase. Group 2, 'HIT', receives HIT without technology support. Group 3, 'MIT', receives MIT, reflecting training intensity as used in usual care. The primary outcome is patient-reported disability, measured by the Modified Oswestry Disability Index. Secondary outcomes include quantitative sensory testing, psychosocial factors, broad physical fitness, quality of life, cost-effectiveness, adherence and usability of technology. Trial registration number NCT06491121.

WHY THIS STUDY IS IMPORTANT

⇒ This pre-registered three armed double blinded multicentred randomised controlled trial will be the first to evaluate the short-term and long-term effectiveness of a time-contingent individualised high-intensity training (HIT) protocol on disability level compared with a time-contingent moderate-intensity training used in usual care, with a long-term follow-up period of 18 months in persons with chronic non-specific low back pain (CNSLBP).

WHAT THIS STUDY ADDS

⇒ This project will provide high-quality, methodologically standardised data on the effectiveness of HIT, while also focusing on underlying fundamental mechanisms, as well as clinical implementation through the evaluation of cost-effectiveness and the potential benefits of extended home-based training with technological support.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This project will provide innovative insights on how to optimise multimodal exercise therapy as a clinical treatment strategy for patients with CNSLBP.

BACKGROUND

Chronic low back pain (CLBP) is one of the most common chronic musculoskeletal disorders worldwide with a prevalence of 20%.[1] Up to 85% of low back pain (LBP) diagnoses are non-specific, meaning no specific cause can be defined and management can be challenging.[2] CLBP is currently ranked as the number one cause of disability.[1] However, the magnitude of disability related to CLBP is not merely determined by the direct impact of pain and discomfort, but also by limitations in daily activities and societal participation.[3 4] For instance, CLBP contributes to 13% of all causes of work absenteeism.[5] In persons with CLBP, sleep disturbances and psychological factors such as anxiety and stress play a role.[6 7] Since psychosocial and emotional factors are strong predictors of LBP chronicity, persons with CLBP may end up in a lifelong vicious circle characterised by invalidating pain, work absenteeism, physical deconditioning, sedentary lifestyle and comorbidities such as obesity or depression.[2 8–10] As a result, CLBP has major socioeconomic implications and creates a burden on our healthcare system with global cost estimations rising substantially each

decade.[11] Optimised CLBP management through innovative research efforts is therefore essential.[12]

State-of-the-art guidelines recommend implementing exercise therapy (ET) in CLBP management.[13] Nevertheless, treatment effect sizes in CLBP remain modest.[13] Different factors may explain this.

First, many studies providing ET in CLBP started from the idea that the back should be treated carefully.[14 15] This often results in exercise intensities below the required level for optimal treatment success and reinforcing anxious thoughts about loading the spine.[16] Nevertheless, recent findings have demonstrated that high-intensity training (HIT) can be a valuable method to improve the effect sizes of concerning short-term and long-term disability and exercise capacity in persons with CLBP.[17 18] However, the short-term and long-term effects of HIT in a large population with severe CLBP need to be investigated.

Second, it is striking to observe the lack of correlation between patients' improvements in pain and disability after ET on the one hand and results on physical outcome measures such as endurance or strength on the other hand.[19] This shows that ET effects in CLBP might not be directly or solely attributable to these changes in the musculoskeletal system.[19] Substantial evidence now points out that ET provides multiple central effects such as psychological, (neuro)physiological and autonomic adaptations.[20 21] In this regard, literature shows a positive effect of HIT on central sensitisation,[22] mental well-being[23] and adaptations of the cardiovascular system.[24] Furthermore, there are indications that the implementation of sufficient exercise intensity and duration is related to better effects on pain.[25 26] To date, it is unknown how ET can be optimised to improve and retain these central modulation effects maximally.

Third, many ET interventions used a pain-contingent approach (progress based on pain), as opposed to a time-contingent approach (progress over time regardless of pain) that is now advised in chronic pain,[27] reinforcing again the message that the spine is vulnerable and that the exercise should be adapted or stopped in case of an increase in pain.[28] A time-contingent HIT programme leads to significant short-term effect sizes to reduce disability in persons with CLBP.[17]

Additionally, long-term exercise programmes can lead to larger effect sizes for pain reduction and to an improved endogenous pain processing.[29 30] Furthermore, it takes weeks to years to achieve behavioural change.[31] From a feasible, cost-efficient perspective, longer ET protocols are preferably executed at home. However, such a training set-up requires clear guidance and support, as treatment compliance is low without it.[32 33] For that reason, technology might support the treatment by encouraging persons with CLBP to keep performing their exercises in their own environment and prolong the rehabilitation process.[34] For example, a video-based protocol is more effective in improving pain, function, kinesiophobia, expectations and several other factors than usual exercise practice at home.[35] Still, it is unclear which duration leads to optimal improvement and the additional value of technology should be further investigated.[36]

Finally, although individualised exercises combined with education are recommended in chronic pain,[14 37] clinicians often fail to implement this in clinical practice.[19] Evidence shows altered brain structure and function in CLBP patients, and an approach including pain neuroscience education to cognitively prepare patients for ET is recommended.[38] Additionally, exercises are often too uniform given the heterogeneity of CLBP patients.[19] Therefore, many patients fail to adhere to their exercises, leading to poor treatment outcomes.[39] Furthermore, the exercise intensity of these non-individualised exercises can, again, be too low for the specific individual. Individualised interventions and personalised guidance to increase patients' adherence and to adapt the intensity accordingly need to be investigated to enhance therapy success.[39]

Therefore, the primary goal of this study is to evaluate the short-term and long-term effectiveness of a time-contingent individualised HIT protocol preceded by pain science education (PSE) on disability compared with moderate-intensity training (MIT) as used in usual care, in persons with severely disabling CLBP. Secondary goals entail evaluating (1) the short-term and long-term effectiveness of HIT on central effects such as psychological, (neuro)physiological and autonomic adaptations, and on broad physical fitness; (2) the additional effects of prolonged HIT at home; (3) the added value of technology through a mobile application that offers support during HIT home training and (4) cost-effectiveness of (technology supported) HIT compared with MIT.

METHODOLOGY

This protocol is reported according to the Standard Protocol Items: Recommendations for Interventional Trials (SPIRIT) guidelines 2013: Explanation and Elaboration: guidance for protocols of clinical trials.[34]

Patient and public involvement

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination plans of our research.

Study design and study setting

A double-blind (outcome assessor and statistical analysis) superiority three-armed multicentre randomised controlled trial will be conducted. Patients with CLBP will be randomly divided (see'Randomisation procedure' section below) into three groups of each 56 participants (Group 1: 'TechnoHIT'; Group 2: 'HIT'; Group 3: 'MIT') and kept naive. For each group, the trial involves a 24-week exercise intervention with a total of 52 rehabilitation sessions (4 educational sessions in the biopsychosocial programme in the first 2 weeks and two physical therapy sessions each week for 24 weeks (n=48

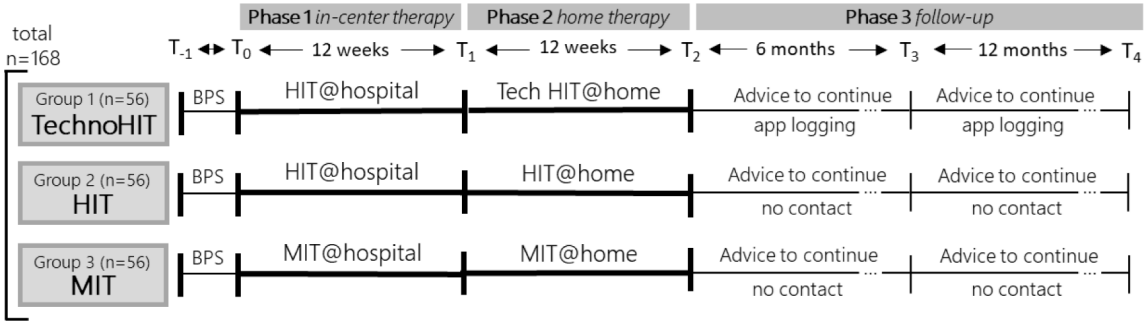

Figure 1 Study design showcasing the different study groups and study phases. HIT, high-intensity training; MIT, moderate-intensity training.

in total)) in three phases (two therapy phases and one follow-up phase). This study will be a collaboration between Universitair ziekenhuis Antwerpen (UZA), Jessa Ziekenhuis, Universiteit Hasselt (UHasselt) and Universiteit Antwerpen (UAntwerpen). An overview of the study design can be found in figure 1.

Timeline

Recruitment will start in May 2024 and the recruitment phase will last approximately 3 years.

Randomisation procedure

The randomisation functionality of the castor data management software[40] will be used to randomise patients into three groups. Participants will not be informed about the approach of the different groups, but they will be informed that the study investigates three different active rehabilitation programmes for CLBP. A rater cross-over assessment protocol will be performed to ensure the assessors are blinded. The assessors will perform baseline measurements and guide the treatment at one clinical site, and follow-up measurements at the other.

Participants

Adult participants[17–64] can be included in the study in case they are diagnosed with severe non-specific CLBP, defined as chronic primary musculoskeletal pain below the costal margin and above the inferior gluteal folds for more than 12 weeks[41] whereby fluctuations in pain can be present. Remission phases can alternate the pain. Participants must have ≥20% on the Modified Oswestry Disability Index (MODI) to be categorised as 'severe'. All inclusion and exclusion criteria can be found in table 1.

Recruitment

Participants who ought to be eligible for the study during consultation at UZA/Jessa, will be informed about this study by the physician or one of the researchers. If they are interested, a study flyer and an approval form for further contact (via email and/or telephone according to the preference of the possible participant) will be issued by the physician. The researchers contact the potential participant within 2–7 days, answer initial questions, review the inclusion criteria and provide informed consent (online/hard copy according to the preference of the potential participant). Patients who sign and return the informed consent within 2 weeks will be contacted for possible enrolment.

Sample size

A sample size calculation (power analysis) was performed with JMP Pro V.14.1 in collaboration with the Center for Statistics (CenStat, UHasselt) based on the therapy effect of a HIT compared with an MIT programme on disability measured with the MODI in persons with CLBP after a 12-week intervention protocol[17] (see online supplemental appendix 1). As the primary aim of this project is to be able to show significant short-term and long-term differences between HIT and MIT (at T1, T2, T3 and T4) on the primary outcome disability assessed by MODI, a sample size calculation for significance level α=0.05 and power level β=0.80 was performed to test the null-hypothesis that MODI outcome is equal for both groups. As a reference for variability, the highest value between estimated values for T2 was taken to ensure that actual project results will be correct for lower variance values. Additionally, the same number of patients was taken for

Table 1 Inclusion and exclusion criteria

Inclusion	Exclusion
18–65 years old	Spinal fusion surgery
Speak Dutch	Interfering musculoskeletal and/or chronic disorder aside from CLBP
Non-specific CLBP for >12 weeks	Severe comorbidities (eg, paresis, sensory disturbances by neurological causes, diabetes mellitus, rheumatoid arthritis)
≥20% on the MODI	Pregnancy
Own a working smartphone (iOS or Android)	Ongoing compensation claims
	Inability to attend regular therapy appointments

CLBP, chronic low back pain; MODI, Modified Oswestry Disability Index.

the other group, resulting in a total sample size of 83. Accounting for a maximum potential total 50% loss-to-follow-up after T4 and an allocation ratio of 1, this results in a sample of 168 patients to be included in this project divided into three groups of 56 participants (Group 1: 'TechnoHIT'; Group 2: 'HIT'; Group 3: 'MIT').

Intervention

At the start of the intervention, all participants will receive four PSE sessions (60 min/session, 2×/week) as part of a biopsychosocial therapy model in groups of 2–5 participants. These sessions will be organised by researchers and occupational therapists at the hospitals, comprising various topics in a PowerPoint presentation. The content of these sessions was developed using scientific literature[42 43] and two online web tools called 'Retrain Pain'[44] and 'Pain Revolution'.[45] Topics vary from neurophysiological pain mechanisms to activity management and debunking ergonomic myths, all aiming to provide insights into the biopsychosocial components of pain, movement and activities of daily living. All three groups will then follow a 12-week training programme in-centre under the supervision of a trained physiotherapist (phase 1) and a 12-week training programme at home (phase 2) (for a detailed display, see online supplemental appendix 1).

Phase 1: in-centre therapy (months 1–3)

Experimental groups ('TechnoHIT' and 'HIT')

Groups 1 and 2 will perform a 12-week time-contingent protocol, previously published,[17] encompassing two 1.5-hour ET sessions weekly in the hospitals. These sessions include cardiorespiratory interval training, general resistance training and core muscle strength training, all at high intensity. The cardiorespiratory protocol will be individualised based on a maximal cardiopulmonary exercise test, and will be executed on a cycle ergometer. On a screen, patients will be able to see their heart rate (HR) and repetitions per minute (RPM). The protocol will consist of five 1 min bouts (110 RPM at 100% VO_2max) alternating with 1 min of active rest (75 RPM at 50% VO_2max). General resistance training includes three upper-body and three lower-body exercises that will be executed on fitness equipment. All exercises will be performed at 80% of the individual 1 repetition maximum (RM) and start at eight repetitions. Individual progressions will be implemented.[46] Core muscle training includes six static core exercises. Exercises will be chosen in function of their ability to load the core muscles at an intensity of >60% of the individual maximum voluntary contraction. Participants will have to perform one set of 10 repetitions of a 10 s hold alternating with 5 s rest.

Control group 'MIT'

Group 3 will perform a similar programme, but at a lower intensity. A continuous cardiorespiratory protocol of 14 min will be executed on a cycle ergometer (90 RPM at 60% VO_2max). During the first 12 sessions, the duration will be increased by 1 min 40 s every two sessions

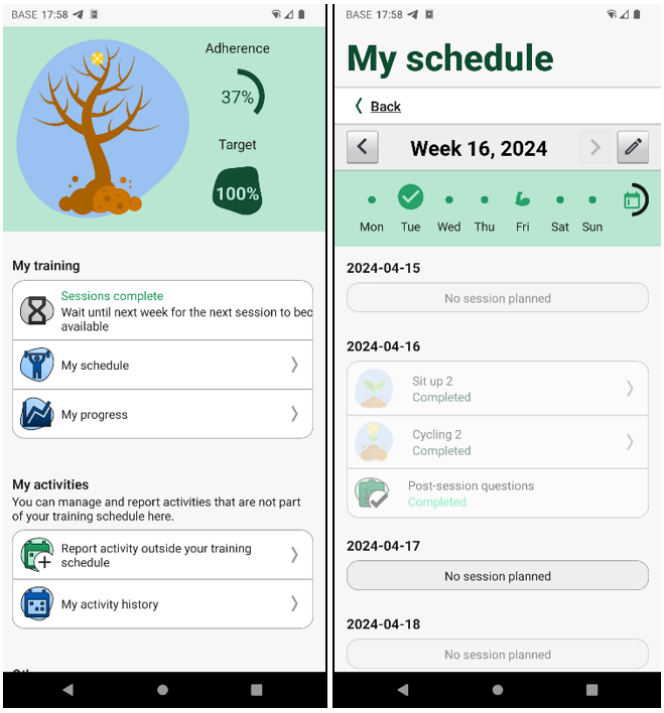

Figure 2 Example of the smartphone application screen.

up to 22 min 20 s. From sessions 13 to 24, the protocol is repeated with an increase in workload (+5% Wmax). General strength exercises and core strength training are identical to the HIT protocol, with the exception of the intensity and repetitions. Participants will perform 15 repetitions of the strength exercises at 60% of 1 RM. The workload will progress every 2 weeks by 5%. Regarding the core exercises, participants will have to perform one set of 10 repetitions of a 10 s hold. The static hold time will be increased every six sessions when executed correctly, and the posture will become more demanding when the core is stable for the indicated time for two consecutive sessions.

Phase 2: at-home therapy (months 3–6)

After completing the first 3 months of the training programme, all three groups will follow a comparable 12-week programme in their home setting. They are asked to perform a 60 min training session two times a week. Groups 1 and 2 receive a fitness bike, a smartwatch, a polar HR sensor and a training mat during this phase. Group 1 will also be guided by a mobile application (figure 2). Training sessions, corresponding to the actual progress of the patient in the HIT training programme, are scheduled in the mobile application in a weekly programme. Instructions with visual representations (drawings or pictures) are given for the specific exercises, and guidance or feedback by the application is momentarily provided while the patient performs the exercises (eg, a countdown with respect to the expected frequency of execution, a timer or a visualisation of a patient's HR). After performing the exercise, the patient reports the completion level

Table 2 Overview of secondary outcome measures

Central pain processing	Specifics
Quantitative sensory testing (QST)—thermal stimulation	QST is a reliable non-invasive examination of the somatosensory system frequently used in pain diagnostics.[48] A standardised test protocol of 30 min makes it possible to acquire patterns of sensory loss and sensory adaptations such as hyperalgesia or allodynia.[49] In particular, advanced thermal stimulation will be assessed with the TSA 2 (Medoc, Israel), including thermal detection thresholds and pain thresholds in a seated position with the thermode placed on the anterior side of the dominant forearm. Each threshold will be assessed four consecutive times. The mean value of the last three measurements will be calculated. This protocol has been used in chronic pain patients and is proven to be valid and reliable.[50] The same assessment will be conducted with the patient in prone position with the thermode placed on the painful area of the lower back. Temporal summation (TS), VAS60 and conditioned pain modulation (CPM) will also be assessed with the TSA 2. CPM will be examined to evaluate the endogenous analgesic system, by examining the change in pain perceived in one body region (anterior side of the dominant forearm) as a result of pain induced in another body region (anterior side of the non-dominant forearm).[48] VAS60 and TS will be measured on the non-dominant forearm
Quantitative sensory testing (QST)—PinPrick-tool	TS will additionally be measured with the PinPrick-tool (MRC systems, Germany) that will be repeatedly applied on the skin on the m. tibialis anterior
Brief Pain Inventory (BPI)	The BPI questionnaire validly assesses severity of pain and its impact on functioning in CLBP. Participants rate their least, worst, average and current pain intensity, and the interference with seven domains of functioning. The body chart of this questionnaire will be used to record extent of pain, using the pain drawing method. Participants are asked to indicate painful areas on the body chart. Extent of pain might indicate the presence of widespread pain, which has been associated with nociplastic pain in chronic joint pain[52]
Psychosocial outcome measure	**Specifics**
Fear Avoidance Components Scale (FACS)	The presence of fear avoidance and pain catastrophising will be evaluated by using the FACS. FACS is a 20-item questionnaire. Each item is scored on a 6-point Likert scale, resulting in scores ranging from 0 ('completely disagree') to 5 ('completely agree'). There is a maximum total score of 100, with higher scores indicating more fear-avoidance. Five severity levels have been proposed: subclinical (0–20), mild,[17 21–39] moderate,[40–59] severe[60–66 80–92] and extreme (81–100). The FACS-D has good reliability and validity in persons with chronic musculoskeletal pain[53]
Brief resilience scale (BRS-NL)	The degree of individual resilience will be assessed using the BRS-NL. The 6 items of this self-report questionnaire are scored on a 5-point Likert scale. A higher score corresponds to being more resilient than a lower score[54]
Tampa scale for kinesiophobia (TSK)	The presence of kinesiophobia will be validly evaluated with the TSK. The TSK is a 17-item questionnaire to assess fear of movement and fear of (re)injury on a 4-point Likert scale ranging from 'strongly disagree' to 'strongly agree'. Items 4, 8, 12 and 16 are inversely phrased. A higher score indicates higher levels of kinesiophobia[55]
Self-efficacy for exercise (SEE)	The SEE is a revision of McAuley's self-efficacy barriers to exercise measure, a 9-item instrument that focuses on self-efficacy expectations related to the ability to continue exercising in the face of barriers to exercise. Prior research demonstrated sufficient evidence for reliability and validity[56]
Expectations to recover (ETR)	Patients will be asked to rate treatment expectations on a 0–10 visual analogue scale
Brief illness perception questionnaire (b-IPQ)	The b-IPQ will evaluate cognitive and emotional representations of illness. It is moderately reliable and consists of 8 items, examining eight areas, and uses a single-item scale approach to assess perception on a 0–10 response scale. A higher score indicates more negative perceptions[57]
Injustice Experience Questionnaire (IEQ)	The IEQ is a questionnaire consisting of 12 items, scored on a range from 0 'not at all' to 4 'all the time'. The total score ranges between 0 and 48 and higher total scores reflect higher levels of perceived injustice. Cut-off scores of 19 and 30 are reported for medium and high levels of perceived injustice, respectively. The validity of the IEQ is sufficient[58]
Positive and negative affect schedule (PANAS)	The PANAS is a well-established 20-item questionnaire, divided into two parts representing positive and negative affect dimensions, used to accurately assess participants' emotional states and fluctuations. Respondents rate each item on a 5-point Likert scale, with the total score calculated by summing the ratings of the ten items in each dimension[59]
Broad physical fitness	**Specifics**
A maximal cardiopulmonary exercise test (CPET)	Exercise capacity will validly and reliably be assessed with a CPET performed on a cycle ergometer (eBike Basic, General Electric GmbH, Germany).[60 61] A low workload gradually increases each minute (30W+15 W/min). Maximal oxygen uptake (VO_2max) and maximal workload through cycling time (min) are evaluated through breath-by-breath gas exchange analysis (MetaMax 3B, Cortex, Germany) and heart rate monitoring (H10, Polar Electro, Finland). A minimum respiratory exchange ratio (RER) threshold of 1.10 is used to evaluate proper validity of the maximum effort
International Physical Activity Questionnaire Short Form (IPAQ-sf)	The IPAQ-sf is a questionnaire consisting of 7 questions, and will measure the physical activity level. A higher score corresponds to a more physically demanding activity level. This questionnaire is reliable and valid for use in persons with CLBP[62]
Heart rate variability (HRV)	HRV will be assessed to evaluate autonomic function. Participants will follow a standardised protocol lasting 30 min, conducted in a quiet low stimulus room. Participants will remain in a supine position for 7 min after which beat-to-beat intervals (R–R) will be recorded using a validated heart rate monitor (H10, Polar Electro) synchronised with a wristwatch (Ignite, Polar Electro).[63] The protocol is based on scientific literature[64 80]
C reactive protein (CRP)	CRP is a well-established marker for systemic inflammation and will be measured with a non-invasive finger-prick blood sampling technique, using the reliable QuickRead Go instrument (see online supplemental appendix 1) (Aidian, Finland)[81 82]
Haemoglobin A1c (HbA1c)	HbA1c will be measured with a non-invasive finger-prick blood sampling technique, using the QuickRead Go instrument (see online supplemental appendix 1) (Aidian, Finland) to assess the average concentration of glucose in the bloodstream over the last 3 months[83]

Continued

Table 2 Continued

Quality of life	Specifics
Work Ability Index (WAI)	The WAI evaluates self-perceived work ability. Patients answer questions divided into seven categories: current work ability compared with lifetime best, work ability in relation to job demands, number of current diseases diagnosed, estimated physical work impairment due to diseases, sick leave during the past year, own prognosis of work ability 2 years from now and mental resources. The total score can range from 7 to 49 points with higher scores indicating better work ability.[84] The WAI has proven to be valid and reliable[85]
Pittsburgh Sleep Quality Index (PSQI)	The PSQI is a 19-item 3-point scale questionnaire that is valid and reliable to measure last month's sleep quality in seven domains: sleep latency time, sleep duration, sleep medication, daytime functioning, sleep-related problems[86]
EuroQOL (EQ5D)	Quality of life will be evaluated using the EQ5D. This validated Dutch questionnaire consists of five dimensions: mobility, self-care, usual activities, pain/discomfort and anxiety/depression. As such, it produces a code which represents a certain health state. The version that will be used (5L) is preferred over the 3L-version as it presents five possible conditions within each dimension in contrast to only 3. As a consequence, the 5L-version is more nuanced and more sensitive to gains (or losses) in general health, which might be especially important for our analyses[87]
Cost effectiveness	**Specifics**
iMTA Productivity Cost Questionnaire (iPCQ)	To evaluate absenteeism at work/loss of productivity, the IPCQ will be used. iPCQ includes three modules measuring productivity losses of paid work due to (1) absenteeism and (2) presentism, and (3) productivity losses due to unpaid work. iPCQ delivers necessary input to calculate costs associated with productivity loss using the Human Capital Approach for short-term absence and Friction Cost Method for long-term absence[88]
Adherence and motivation	**Specifics**
Exercise Adherence Rating Scale (EARS)	EARS is a valid and reliable 17-item questionnaire that measures the adherence to prescribed home exercises. Six items assess adherence behaviour, while the remaining 11 items assess reasons for adherence or non-adherence. 16 items are scored using a 5-point Likert scale with a high score indicating higher adherence[89]
Intrinsic Motivation Inventory (IMI)	The IMI is a nominal 35 items 7-point questionnaire that assesses the multidimensional subjective experience while performing a certain activity yielding six subscales (interest/enjoyment, perceived competence, effort, value/usefulness, felt pressure and tension, and perceived choice), with the possibility of independent scoring for each scale and a general scoring. A higher score correlates to higher intrinsic motivation (total range 35–245)[90]
Usability of technology	**Specifics**
System Usability Scale (SUS)	SUS is a standard 10-item questionnaire in which responses are measured on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Questions 1, 3, 5, 7 and 9 are positive and questions 2, 4, 6, 8 and 10 are negative. A total SUS score is derived by summing the individual scores and multiplying by 2.5, which yields a score ranging between 0 (worst) and 100 (absolute best). A score >68 is considered above average usability and >80 is considered high usability and a level at which participants are likely to recommend the product to peers[91]
User Version of the Mobile Application Rating Scale (uMARS)	uMARS is a 20-item questionnaire that includes four objective quality subscales: engagement, functionality, aesthetics and information quality, and one subjective quality subscale. Each item is scored on a 5-point Likert scale. Both individual items as well as a mean overall score can be used for evaluation[92]

for that exercise. This way, the application calculates adherence to the training programme over time. Motivational feedback is given based on the patient's performance. Based on the achieved adherence, the application will attempt to predict whether additional guidance is needed and whether alternative strategies to increase adherence are recommended.

A web-based dashboard application supports the researchers, who will be able to monitor every individual and send out personalised feedback or tips. The dashboard allows managing patient inclusion with an authorised account. Individual patient files can be retrieved to change the training programme (so the set of exercises and their parameters such as difficulty level) based on suggestions by the system.

Groups 2 and 3 receive an exercise schedule on paper and a diary to log their training sessions. Group 3 will be asked to replace the cardiorespiratory protocol on the bike by performing a brisk walking modality. As the goal is to represent usual care as much as possible, this group will not be provided with a bicycle or exercise mat.

Phase 3: follow-up (month 6 until 18 months follow-up)

All participants are advised to continue their exercise programme at home. The researchers do not contact them during this phase. Participants of the Technology supported High Intensity Training (Techno-HIT) group are allowed to continue using the app at their initiative. At months 6 and 18 after the intervention, the participants will be reassessed to collect follow-up data.

Outcome measures

Outcome measures will be collected at baseline (T−1 and T0) and at 12 weeks (T1), 24 weeks (T2), 1 year (T3) and 2 years (T4). The primary outcome is the change in the MODI score from baseline to follow-up. The MODI is a self-report questionnaire comprising 10 items scored on a 5-point Likert scale. The total score will be noted on a scale of 0–100 with higher scores indicating higher levels of disability. It has good clinimetric properties to evaluate disability experienced by people in their daily activities due to CLBP.[17] Secondary outcome measures including quantitative sensory testing, psychosocial outcome

Table 3 Schedule of enrolment, interventions and assessments in accordance with the SPIRIT 2013 guidelines

	Study period							
	Enrolment	Allocation	Post-allocation				Follow-up	
							Phase 3	
Timepoint	T–1	T0	Phase 1 (in centre)	T1	Phase 2 (at home)	T2	T3	T4
Enrolment								
Eligibility screening	X							
Informed consent	X							
Allocation		X						
Interventions								
Techno-HIT			X		X			
HIT			X		X			
MIT			X		X			
Assessments								
Patient demographics	X							
MODI	X	X		X		X	X	X
QST	X	X		X		X	X	X
BPI	X	X		X		X	X	X
FACS	X	X		X		X	X	X
BRS-NL	X	X		X		X	X	X
TSK	X	X		X		X	X	X
SEE	X	X		X		X	X	X
ETR	X	X		X		X	X	X
b-IPQ	X	X		X		X	X	X
IEQ	X	X		X		X	X	X
PANAS	X	X		X		X	X	X
CPET		X		X		X	X	X
IPAQ-sf		X		X		X	X	X
HRV	X	X		X		X	X	X
CRP	X	X		X		X	X	X
HbA1c		X		X		X	X	X
WAI	X	X		X		X	X	X
PSQI		X		X		X	X	X
EQ5D		X		X		X	X	X
In-hospital costs				X		X	X	X
IPCQ				X		X	X	X
Healthcare utilisation costs							X	X
Number of completed therapy sessions				X		X	X	X
EARS				X		X	X	X
IMI						X	X	X
SUS*						X	X	X
UMARS*						X	X	X

*Only for participants of the Techno-HIT group.
b-IPQ, Brief Illness Perception Questionnaire; BPI, Brief Pain Inventory; BRS-NL, Brief Resilience Scale-NL; CPET, cardio-pulmonary exercise test; CRP, C reactive protein; EARS, Exercise Adherence Rating Scale; EQ5D, EuroQOL; ETR, expectations to recover; FACS, Fear Avoidance Components Scale; HbA1c, haemoglobin A1c; HIT, high-intensity training; HRV, heart rate variability; IEQ, Injustice Experience Questionnaire; IMI, Intrinsic Motivation Inventory; IPAQ-sf, International Physical Activity Questionnaire Short Form; IPCQ, iMTA Productivity Cost Questionnaire; MIT, moderate-intensity training; MODI, Modified Oswestry Disability Index; PANAS, positive and negative affect schedule; PSQI, Pittsburgh Sleep Quality Index; QST, quantitive sensory testing; SEE, self-efficacy for exercise; SPIRIT, Standard Protocol Items: Recommendations for Interventional Trials; SUS, System Usability Scale; Techno-HIT, Technology supported High Intensity Training; TSK, Tampa Scale of Kinesiophobia; UMARS, User Version of the Mobile Application Rating Scale; WAI, Work Ability Index.

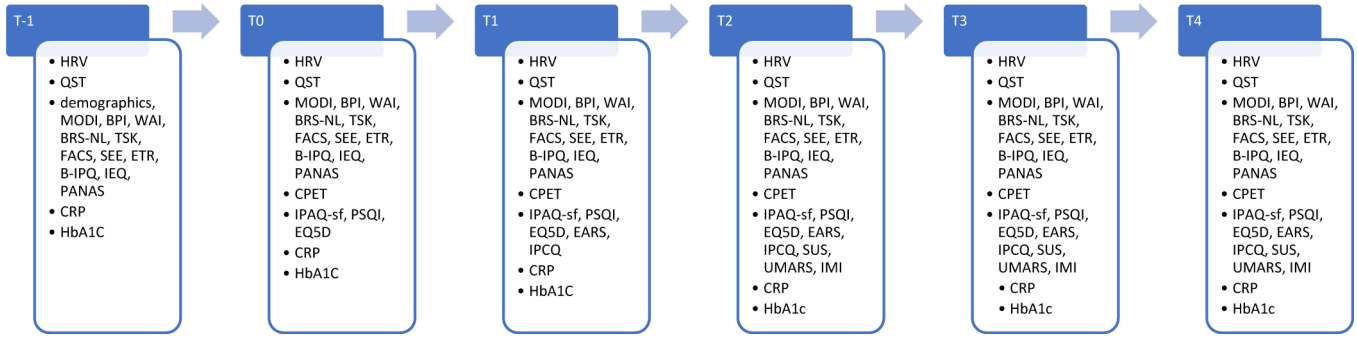

Figure 3 Chronological overview assessments. B-IPQ, Brief Illness Perception Questionnaire; BPI, Brief Pain Inventory; BRS-NL, Brief Resilience Scale-NL; CPET, cardio-pulmonary exercise test; CRP, C reactive protein; EARS, Exercise Adherence Rating Scale; EQ5D, EuroQOL; ETR, expectations to recover; FACS, Fear Avoidance Components Scale; HbA1C, haemoglobin A1C; HRV, heart rate reliability; IEQ, Injustice Experience Questionnaire; IMI, Intrinsic Motivation Inventory; IPAQ-sf, International Physical Activity Questionnaire Short Form; IPCQ, iMTA Productivity Cost Questionnaire; MODI, Modified Oswestry Disability Index; PANAS, positive and negative affect schedule; PSQI, Pittsburgh Sleep Quality Index; QST, quantitative sensory testing; SEE, self-efficacy for exercise; SUS, System Usability Scale; TSK, Tampa Scale of Kinesiophobia; UMARS, User Version of the Mobile Application Rating Scale; WAI, Work Ability Index.

measures, broad physical fitness, usability of technology, adherence and motivation, cost-effectiveness and quality of life are listed in table 2 (for a detailed display, see online supplemental appendix 1).

All assessments will be conducted by trained researchers at two location sites, namely at the MOVANT Research Labs, UAntwerpen and REVAL Research Labs, UHasselt (Belgium). Physical assessments are performed following standardised protocols. Participants will be asked to fill in questionnaires in a quiet room. To limit the cognitive burden as much as possible, starting at T0, all questionnaires will be divided into two parts, separated by a physical assessment. Participants also have the option to take a 15 min break. An in-detail schedule of enrolment, intervention and assessments can be found in table 3, according to the SPIRIT 2013 guidelines.[47] All assessments will be conducted predetermined, as shown in figure 3.

Data analysis and statistics

Data will be collected and logged consistently through the Castor data management software[40] to ensure full data traceability throughout the study. Data analysis will be performed in JMP Pro (V.14.0, SAS Institute, Cary, USA). It will first be checked whether the data are normally distributed to determine whether parametric or non-parametric analyses should be performed.

For baseline assessment analyses, T−1 to T0 PSE session effects (PRE-POST) will be analysed with a dependent t-test/Wilcoxon signed-rank test to evaluate the impact of education on pain processing in this population. Second, baseline T0 data will be analysed to determine descriptive statistics for the different outcome measures for each group. Third, correlation analysis (linear multiple regression analysis) will be performed to determine associations between disability and pain processing.

For longitudinal assessment analyses, to evaluate the effectiveness of the HIT versus MIT intervention on T1 and the effectiveness of the Techno-HIT versus HIT versus MIT intervention on T2, different versions of linear mixed models will be considered (random intercept; random intercept, random slope with different covariance structure; dependent errors; transformed versions of responses; with unstructured times) and the version with the best fit to the data will be used for the analysis. Multiple comparisons will be executed to evaluate group (baseline differences), time (within-group differences) and interaction effects (between-group differences). For all tests of significance, an α-level=0.05 will be used. To account for bias due to deviations from intended interventions (drop outs), both an intention-to-treat (to evaluate the effect of assignment to the interventions at baseline, regardless of whether the interventions are received as intended) and a per-protocol analysis (to evaluate the effect of adhering to the interventions as specified in the trial protocol) will be performed. The intention-to-treat analysis will use a multiple imputation technique under the assumption of values missing at random. To check for selective drop-out, differences between participants completing the trial and drop-outs will be examined (independent t-tests, Mann-Whitney U tests, χ^2 tests). The researcher performing these statistical analyses will be blinded as he/she will only receive a coded version of the data containing no personal identification data.

Clinical relevance, strengths and limitations

Clinical relevance

HIT has already been found feasible and effective in decreasing disability in moderate CLBP[18] and in several other chronic disorders such as chronic neck pain, axial Spondyloarthritis, multiple sclerosis, and chronic lung and heart diseases.[65–69] However, this is the first clinical study to evaluate the impact of HIT in a larger spectrum of persons with severe CLBP in a rehabilitation centre setting, and this study is essential to increase the external

validity of HIT as a general rehabilitation strategy. Results will be transferable to different chronic pain populations, and this could potentially be a big step forward in the future biopsychosocial treatment of chronic pain.

Furthermore, this study will investigate the added value of longer training programmes and technological support during the follow-up training phase at home.

This study will fill the gap in the literature on the underlying working mechanisms of HIT. HIT shows promising results in CLBP patients.[17] However, it is unclear how. One hypothesis is a change in psychosocial factors. For instance, general mental health increases after ET in numerous chronic musculoskeletal disorders.[19 70] This is an important finding, as factors such as patients' expectations to recover and self-efficacy to cope with a disorder, are clear therapy success modulators in CLBP.[71 72] Furthermore, HIT causes an increase in self-efficacy,[73] supporting this theory. Another possibility is a change in (neuro)physiological factors including improved anti-inflammatory factors that accompany the increased physical demands of HIT.[74] On the other hand, the role of ET in activating the endogenous pain system, often dysfunctional in persons with chronic pain,[20 75 76] has been displayed in various populations.[77 78] Research is necessary to improve and retain these central effects.

Strengths and limitations

The study population will include adult severe CLBP patients, diagnosed by their general practitioner or the physician at the Department of Physical Medicine and Rehabilitation. These eligible patients will be referred to and contacted by the researchers. This multidisciplinary diagnostic process is a major strength of this study. One of the challenges of this study is insufficient patient enrolment. However, CLBP is one of the most prevalent musculoskeletal disorders,[1] and disability seems to be the most determinant factor in seeking help and consulting a doctor to manage their pain.[79] Additionally, patient recruitment will occur at different centres in Belgium (UZA and Jessa) and there is a possibility to contact other hospitals if necessary.

As a consequence to the long duration period and the extensive assessments during baseline and follow-up measurements, the risk for drop-out can be high. However, there are indications that sufficient duration is related to improved effects on pain,[25 26] and patients will be motivated by the physiotherapists to finalise the full treatment programme and follow-up measurements. In previous research, we showed that time-contingent HIT leads to substantially higher short-term effect sizes to reduce disability in comparison to therapy as usual in a randomised controlled trial consisting of persons with CLBP with mild/moderate disability and good psychosocial health.[17] We expect that patients who experience good treatment results will be encouraged to complete the full programme, especially considering the long follow-up period and the technology supported motivational programme in the TECHNO-HIT group. Nevertheless, a potential loss-to-follow-up of 50% was calculated in our sample size calculation.

Due to the nature of the therapy, the physiotherapist who gives the treatment cannot be blinded. The variability of the caregivers supervising the treatment could influence the standardised working method of the study. However, this increases the transferability to the clinical practice, since preferred working methods can differ between different caregivers in the clinical setting. Moreover, rehabilitation programmes in a hospital setting are generally guided by multiple physiotherapists.

To optimise the standardisation, a manuscript with the intervention protocol, exercises and progressions will be provided to the caregivers. A detailed script with assessment protocols will additionally be set up by the researchers who perform all measurements to ensure a standardised working method.

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Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by The study protocol and smartphone application are ethically approved by FAGG ('consolidated opinion Federal Agency for Medicine and Health Products (AMHP) (Ref. CIV-23-12-045154) and by the medical ethical committees of University hospital Antwerp (UZA) (EC 6234), Jessa Hospital Hasselt (Jessa) (ID 024/047 - TECHNO-HIT trial), University of Hasselt (UHasselt) and University of Antwerp (UAntwerpen). This randomised controlled trial will adhere to Good Clinical Practice (ICH-GCP E6R2) regulations. The study was pre-registered at clinicaltrials.gov NCT06491121. Participants gave informed consent to participate in the study before taking part.

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