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Maximal aerobic capacity is associated with lifting capacity, but not with self-reported functioning measures in patients with primary chronic low back pain: a cross-sectional study

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ABSTRACT

Objective Maximal exercise testing is considered the gold standard to assess $\dot{V}O_2$max. However, maximal exercise testing was previously deemed unfeasible and unsafe in chronic low back pain (CLBP) patients. Consequently, most previous studies on aerobic capacity and functioning in patients with CLBP were performed with submaximal testing protocols. A recent study demonstrated the safety, feasibility and tolerance of maximal exercise testing in patients with CLBP. Therefore, the relation between aerobic capacity and functioning should be reevaluated. This cross-sectional study aims to determine the relationship between maximal aerobic capacity and four measures of functioning: lifting capacity, work ability, pain-related disability and physical functioning in patients with CLBP.

Methods The maximal aerobic capacity of patients with CLBP was assessed with a maximal cardiopulmonary exercise test. Functioning was measured with a floor-to-waist lifting capacity test and three questionnaires: Work Ability Score, Pain Disability Index and Physical Functioning subscale of RAND-36. The associations between maximal aerobic capacity and each of the functioning measures were analysed with multiple linear regression analyses while controlling for potential confounders.

Results Data of n=74 patients with CLBP were analysed. After controlling for potential confounders, maximal aerobic capacity was moderately associated with lifting capacity (β=0.32, p=0.006), but not with any of the other functioning measures (β=−0.08 to 0.12, p>0.288).

Conclusion A higher level of maximal aerobic capacity is moderately associated with a higher lifting capacity, but not with self-reported work ability, pain-related disability and physical functioning.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Chronic low back pain (CLBP) has negative psychosocial and physical effects on patients and decreases functioning and disability.

⇒ Safety, feasibility and tolerability of a maximal cardiopulmonary exercise test were established in patients with CLBP.

WHAT THIS STUDY ADDS

⇒ Our study shows that maximal aerobic capacity is positively associated with objectively measured lifting capacity in patients with primary CLBP, but not with self-reported work ability, pain-related disability and physical functioning.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE AND/OR POLICY

⇒ Personalised aerobic capacity training could be considered to improve the lifting capacity of patients with primary CLBP.

INTRODUCTION

Primary chronic low back pain (CLBP) has negative psychosocial and physical effects on patients and decreases functioning and disability.[1 2] In patients with CLBP, a higher level of physical activity is associated with higher physical functioning and lower pain-related disability.[3–7] Patients with CLBP may be deconditioned due to reduced physical activity, resulting in low maximal aerobic capacity ($\dot{V}O_2$max).[8 9] Most research investigating the relationship between maximal aerobic capacity and functioning in patients with CLBP is performed using submaximal cardiopulmonary exercise testing (CPET).[8 10 11] These studies provide inconsistent results on the relation between maximal aerobic capacity and functioning, pain and disability. Furthermore, submaximal CPET is inaccurate and invalid to determine maximum aerobic capacity because $\dot{V}O_2$max is estimated and not measured directly.[12–14] Consequently, the results of previously reported studies may be flawed. A maximal CPET, although considered the gold standard,[15] has only seldomly been applied because it was not considered feasible or tolerated by patients with CLBP.[14]

Recently, however, feasibility and tolerance of maximal CPET were established in patients with CLBP.[9] It was demonstrated that 69.3%–91.1% of the participating patients with CLBP managed to complete a maximal CPET.[16] One study used maximal CPET and showed the absence of a relation between maximal aerobic capacity and several self-reported measures of functioning and disability.[17] Recently the relationship between maximal aerobic capacity and disability in patients with complaints of arm, neck and/or shoulder was explored.[18] With maximal CPET being in reach for use in patients with CLBP, the current knowledge on the relationship between maximal aerobic capacity and functioning should be re-examined and expanded.

The research question in this study was: what is the relationship between maximal aerobic capacity acquired by maximal CPET and functioning in patients with CLBP? Functioning was operationalised by four measures: lifting capacity, work ability, pain-related disability and physical functioning. It was expected that patients with CLBP with higher maximal aerobic capacity would have higher levels of functioning. Results of this study can be used to reassess current knowledge on this relationship and may result in new insights into treatment options for patients with CLBP.

METHODS AND MATERIALS

Study design

An observational study with a cross-sectional design was conducted from September 2017 to June 2019 in the Center for Rehabilitation of the University Medical Center Groningen (CvR-UMCG) in the Netherlands. This study is part of an extensive project of which the protocol is described elsewhere.[19] Medical ethical approval was obtained from the Medical Research Ethics Committee of the UMCG (METc 2016/702), and procedures are in accordance with the declaration of Helsinki.[20]

Participants

Patients between the age of 18 and 65 years at the time of recruitment who were primarily referred to the CvR-UMCG due to CLBP, deemed mentally competent and capable of following instructions, were eligible for the study. Exclusion criteria were the following: patients not having primary CLBP,[2] but a specific diagnosis that would specifically or potentially account for their CLBP symptoms (eg, herniated disc, acute trauma, a history of cancer or osteoarthritis) based on their medical file, a neuralgia and/or radicular pain in the legs, a severe psychiatric condition, a contraindication to CPET or the lifting capacity protocols,[21–23] being pregnant or planning to be during the study.

Procedure

All data were collected at the baseline assessment of an interdisciplinary pain rehabilitation programme. All participants were informed about the study's measurements and signed informed consent before the start of the study.

Measurements

Maximal aerobic capacity was measured through a CPET. CPET was performed with a cycle ergometer (Ergoselect 200p or Ergoselect 200k, Ergoline, Bitz, Germany) following a defined continuous ramp protocol. Patients started with an unloaded warming-up for 3minutes at 60–70 rotations per minute before the test began. Depending on the estimated patient's level of fitness based on clinical characteristics including but not limited to age, BMI, and smoking behaviour, an experienced exercise physiologist and a specialised physician or nurse determined the starting workload (25–100 watts) and ramp (5–25 watts). During the test, the workload was progressively increased every 3minutes in steps of the predetermined ramp. At the same time, the patient was asked to maintain a constant cadence until their maximum performance was reached. Maximum performance was determined by several variables: a temporary loss of strength and energy (=exhaustion), a plateau in peak oxygen uptake in mL/min, a respiratory exchange ratio higher than 1.15 and/or a heart rate higher than 85% of the maximal predicted heart rate.[21] The plateau in peak oxygen uptake was determined by plotting $\dot{V}O_2$ against external workload. As $\dot{V}O_2$ increases with the increasing external workload, one or more of the determinants of $\dot{V}O_2$ approach limitations (eg, stroke volume, heart rate or tissue extraction) and $\dot{V}O_2$ versus work rate may begin to plateau. Achieving a clear plateau in $\dot{V}O_2$, meaning a variation of ≤2mL/kg/min with respect to the $\dot{V}O_2$ value from the last test charge increment, has traditionally been used as the best evidence of $\dot{V}O_2$max.[21 24–26] During the test, patients were monitored on their cardiac activity with an ECG, blood pressure with a blood pressure cuff and their ventilatory gases on a breath-by-breath basis with a metabolic cart (JAEGER Vyntus CPX, Jaeger, Germany, Hoechberg). The peak oxygen uptake in mL/min ($\dot{V}O_2$max) was obtained as the mean of $\dot{V}O_2$ over the last 30seconds of the test.

Lifting capacity was measured with a floor-to-waist lift capacity test based on the Work-Well Functional Capacity Evaluation protocol.[22] The lift test has high test–retest (one-way random intraclass correlation coefficient (ICC)=0.81) and inter-rater reliability (CR-10 ratings ICC=0.76) in patients with CLBP.[27 28] Assessors trained in the test procedure provided standardised instructions to repetitively lift a crate with weights from a shelf at waist height to the floor and back. The test started with a weight that could easily be lifted, followed by a progressive increase in load. The tests ended when maximum capacity was reached. The endpoint was determined by various parameters, whichever came first: cardiac endpoint (85% of maximum heart rate), biomechanical endpoint (unsafe increasing weight because of lack of load handling control), patient endpoint (patient decides to stop) and criterion endpoint (normal end of

the test).[29] The maximal load lifted was recorded in kilograms.

Work ability was measured using the Work Ability Score (WAS), a single-item question comparing patients' lifetime best work ability with their current work ability. The WAS ranges from 0 (unable to work) to 10 (best working ability). The single-item question is part of the Work Ability Index (WAI). This questionnaire measures work ability and has shown to be test–retest reliable (difference between test and retest=−0.53 in construction workers).[30] The WAS is highly correlated to the 28 items of the WAI among women on long-term sick leave (r=0.87)[31] and among active workers (r=0.63).[32]

Pain-related disability was measured with the Pain Disability Index (PDI), a questionnaire containing seven items.[33] It measures the interference of pain in daily functioning and life activities: family/home responsibilities, recreation, social activities, occupation, sexual behaviour, self-care and life support activities. Each item ranges from 0 (no interference) to 10 (maximal interference). The sum score ranges from 0 to 70, where a higher score means more interference in daily life.[19] In this study, the Dutch translation of the PDI was used, which has shown a good internal consistency (Cronbach's α=85) and test–retest reliability (one-way random ICC=0.76) in patients with musculoskeletal pain.[34]

Physical functioning was measured through the physical functioning subscale of the RAND-36 (RAND-36 PF) questionnaire. Patients answered ten questions about the limitations they experience during their daily activities. The sum score ranges from 0 to 100, where a higher score indicates a greater level of self-reported limitations.[19] The Dutch translation was used, which has shown good internal consistency (Cronbach's α=0.92) and test–retest reliability (r=0.72–0.82) in the general population.[35]

Clinical information was collected by means of questionnaires, all of which are explained in more detail elsewhere[19]: pain intensity (Visual Analogue Scale-pain, 0–10),[36] catastrophising (Pain Catastrophising Scale, 0–52),[37] perceived injustice (Injustice Experience Questionnaire, 0–48)[38] and psychological traits (Brief Symptom Inventory Global Severity Index T-score, 0–100).[39] In all these questionnaires, higher scores represent worse states. For each patient, age, sex, height, weight, pain symptoms characteristics (diagnosis area and duration), educational level and employment details (physical work demands per Dictionary of Occupational Titles)[40] were collected with a custom-made form.

Table 1 Description of participating patients

	N	Mean	SD/%
Age (years)	74	40.4	±12.4
Sex	74		
Male	30		40.5%
Female	44		59.5%
BMI (kg/m^2)	74	27.7	±5.4
Diagnosis area	74		
Low back	24		32.4%
Generalised back	23		31.1%
Back and legs	10		13.5%
Multiple sites	17		23.0%
Educational level	70		
Primary	2		2.9%
Secondary	40		57.1%
Higher	28		40.0%
Physical work demands	74		
Sedentary	18		24.3%
Light	32		43.2%
Medium	20		27.0%
Heavy	4		5.4%
Pain intensity (VAS; 0–10)	73	4.7	±2.2
Catastrophising (PCS; 0–52)	65	18.9	±10.2
Injustice (IEQ; 0–48)	70	16.8	±9.7
Distress (BSI-GSIT; 0–100)	65	39.7	±9.2
$\dot{V}O_2$max (l/min)	74	2.0	±0.6
Male	30	2.4	±0.7
Female	44	1.8	±0.3
Lifting capacity (kg)	72	14.4	±9.4
Male	30	20.1	±9.9
Female	42	10.2	±6.5
Work ability (WAS; 0–10)	73	4.6	±2.4
Pain-related disability (PDI; 0–70)	72	36.7	±11.9
Physical functioning (RAND-36 PF; 0–100)	73	51.5	±19.5

BMI, body mass index; BSI, Brief Symptom Inventory; GSIT, Global Severity Index Total Score; IEQ, Injustice Experience Questionnaire; PCS, Pain Catastrophising Scale; PDI, Pain Disability Index; PF, physical functioning; VAS, Visual Analogue Scale; $\dot{V}O_2$max, maximal aerobic capacity; WAS, Work Ability Score.

Statistical analysis

The sample size was estimated at 63 participants as calculated with GPower (G*Power for Windows, V.3.1.9.7) with an alfa error of 0.05 and a power of 0.85. Before any analysis was done, data were prepared as described in the protocol published elsewhere.[19] The data analysis was performed with SPSS software V.25.0 (IBM).

Data distribution was assessed by using the Kolmogorov-Smirnov test and skewness and kurtosis. Data not normally distributed were analysed with non-parametric tests. Differences in maximal aerobic capacity and lifting capacity between males and females were evaluated using two-tailed independent samples t-tests. Correlation coefficients were generated using bivariate correlation analyses to explore relationships between main measures (maximal aerobic capacity, lifting capacity, work ability, pain-related disability and physical functioning) and

Table 2 Results of correlation analyses of the associations of maximal aerobic capacity and lifting capacity, work ability, pain-related disability and physical functioning with demographic and clinical characteristics

	$\dot{V}O_2$max (L/min) n=74		Lifting capacity (kg) n=72		Work ability (WAS) n=73	Pain-related disability (PDI) n=72	Physical functioning (RAND-36 PF) n=73
	Male	Female	Male	Female			
$\dot{V}O_2$max (L/min)	–	–	0.35	0.29	0.23	−0.13	0.17
Sex*	–	–	–	–	−0.02	0.06	−0.02
Age (years)	−0.44*	−0.37*	−0.10	−0.05	0.00	−0.01	−0.21
BMI (kg/m^2)	−0.06	−0.07	−0.10	−0.19	−0.17	0.10	−0.33**
Diagnosis area	0.15	−0.12	−0.06	0.13	−0.24*	0.25*	−0.09
Pain duration (years)	−0.18	0.38*	−0.07	−0.02	0.11	0.00	0.00
Education level	0.50**	0.19	0.41*	0.10	0.35**	−0.14	0.18
Work demands	−0.49**	0.09	−0.14	0.08	0.07	0.11	−0.20*
Pain intensity (VAS)	−0.17	−0.03	−0.31	−0.08	−0.36**	0.41**	−0.35**
Catastrophising (PCS)	−0.09	−0.14	−0.04	−0.35*	−0.18	0.16	−0.26*
Injustice (IEQ)	−0.06	−0.21	0.11	−0.38*	−0.21	0.25*	−0.21
Distress (BSI-GSIT)	−0.17	0.00	0.20	−0.20	−0.27*	0.29*	−0.07

Correlation significance: *P<0.05 ; **p<0.01.
*0=male, 1=female.
BMI, body mass index; BSI, Brief Symptom Inventory; GSIT, Global Severity Index Total Score; IEQ, Injustice Experience Questionnaire; PCS, Pain Catastrophising Scale; PDI, Pain Disability Index; PF, physical functioning; VAS, Visual Analogue Scale; $\dot{V}O_2$max, maximal aerobic capacity; WAS, Work Ability Score.

potential confounders (demographic and clinical characteristics). Bivariate correlations were explored using Pearson correlation for continuous normally distributed data, Spearman's r for continuous not normally distributed and categorical data, and Pearson's Point-Biserial for dichotomous data. Associations with a significance level of p<0.05 were considered potential confounders and were added to the regression analyses. If a bivariate correlation was significant in males or females, the potential confounder was added to the regression analysis. Correlation coefficient values >0.70 were considered strong, values between 0.30 and 0.70 moderate, and values <0.30 weak.[41]

Four multiple linear regression analyses were performed. Lifting capacity, work ability, pain-related disability and physical functioning were the dependent variables, whereas maximal aerobic capacity and potential confounders were the independent variables. Dummy variables were created for categorical data and used as a group in the analyses. A backward selection method was applied, and the least significant variables were manually excluded. The criterion for removal was Fchange >0.05. For the final regression analyses, the enter method was used. Multicollinearity was checked with the variance inflation factors. Statistical significance was assumed when p<0.05.

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.

RESULTS

A total of 97 patients with CLBP enrolled in the study. Five patients declined participation, and fifteen patients were not assessed due to not proceeding to rehabilitation programme treatment. Additionally, one patient was retrospectively excluded because of an existing condition interfering with measurements, and two patients did not perform maximal CPET assessment. Eventually, 74 patients were included in our analyses. No adverse events occurred.

All missing data were accounted for, and missing values were not imputed. Kolmogorov-Smirnov and skewness and kurtosis revealed normal distribution for all variables, except for 'Pain duration (in years)' (median: 2.1, IQR: 1.3–4.2). All other demographic and clinical characteristics are presented in table 1. T-tests revealed higher maximal aerobic capacity and lifting capacity in males than in females (p<0.01). In all other variables, differences between sexes were non-significant (p>0.05).

Results of the correlation analyses between maximal aerobic capacity, lifting capacity, work ability, pain-related disability and physical functioning on the one hand, and demographic and clinical characteristics, on the other hand, are presented in table 2. When correlations were significant, their strengths were weak to moderate.

Results of the regression analyses with lifting capacity, work ability, pain-related disability and physical functioning as dependent variables, respectively, are presented in table 3. The final model for lifting capacity explained 35% of the variance. Both maximal aerobic capacity and sex were significant contributors to the model. The final

Table 3 Final multiple linear regression models of the association between four determinants of functioning and maximal aerobic capacity and potential confounders

Model	β	Unst. β	95% CI	P value	R^2
Lifting capacity (kg)					
(Constant)	–	7.83	(–1.31 to 16.98)	0.092	0.35
$\dot{V}O_2$max (L/min)	0.32	5.24	(1.57 to 8.90)	0.006	
Sex*	–0.37	–6.93	(–11.16 to –2.70)	0.002	
Work ability					
(Constant)	–	4.50	(0.93 to 8.06)	0.014	0.38
$\dot{V}O_2$max (L/min)	0.12	0.49	(–0.43 to 1.41)	0.288	
Educational level	0.33	1.42	(0.45 to 2.39)	0.005	
Distress (BSI-GSIT)	–0.33	–0.09	(–0.14 to –0.03)	0.003	
Diagnosis area: generalised back†	–0.06	–0.31	(–1.58 to 0.97)	0.629	
Diagnosis area: back and legs†	–0.42	–2.85	(–4.46 to –1.23)	0.001	
Diagnosis area: multiple sites†	–0.29	–1.61	(-2.97 to –0.25)	0.021	
Pain-related disability					
(Constant)	–	29.93	(18.19 to 41.67)	0.000	0.18
$\dot{V}O_2$max (l/min)	–0.08	–1.75	(–6.36 to 2.86)	0.452	
Pain intensity (VAS)	0.40	2.18	(0.99 to 3.37)	0.001	
Physical functioning					
(Constant)	–	89.99	(59.85 to 120.14)	0.000	0.23
$\dot{V}O_2$max (L/min)	0.09	2.95	(–4.37 to 10.26)	0.425	
Pain intensity (VAS)	–0.34	–2.97	(–4.84 to –1.11)	0.002	
BMI (kg/m^2)	–0.30	–1.10	(–1.88 to –0.32)	0.006	

*0=male, 1=female.
†Reference category: low back.
BMI, body mass index; BSI, Brief Symptom Inventory; GSIT, Global Severity Index Total Score; VAS, Visual Analogue Scale; $\dot{V}O_2$max, maximal aerobic capacity.

model for work ability explained 38% of the variance. Maximal aerobic capacity did not significantly contribute to the model, while the diagnosis area (back and legs, and multiple sites), educational level and distress did. The final model for pain-related disability explained 18% of the variance. Maximal aerobic capacity did not significantly contribute to the model, while pain intensity did. The final model for physical functioning explained 23% of the variance. Maximal aerobic capacity did not significantly contribute to the model, while body mass index and pain intensity did.

DISCUSSION

Results show that maximal aerobic capacity is positively associated with lifting capacity in patients with CLBP, but not with work ability, pain-related disability and physical functioning. Because this study is one of the first to use maximal CPET to measure maximal aerobic capacity, comparison with results from other studies is hindered. Indirect comparisons can be made with studies using submaximal exercise tests, different study populations or other measures of functioning. The absence of a relation between maximal aerobic capacity and self-reported measures of functioning is consistent with other studies using both submaximal CPET and maximal CPET to determine maximal aerobic capacity.[8 10 11 17] Our study, in which maximal CPET was used, strengthens the overlapping conclusion of the absence of the relation between maximal aerobic capacity and self-reported measures of functioning, drawn in these previous studies using submaximal CPET. Our finding that maximal aerobic capacity is related to lifting capacity is not consistent with the results of the one other study that applied maximal CPET.[17] However, in our study, lifting capacity was objectively measured, whereas in this study, physical functioning was a self-reported measure. Our results are consistent with the findings of one study using submaximal CPET to determine the relation between maximal aerobic capacity and objectively tested functioning.[11]

The absence of a correlation between maximal aerobic capacity and self-reported work ability, pain-related disability and physical functioning might be attributed

to several possible reasons. First of all, these variables of functioning are self-reported and not measured through performance-based testing.[42 43] Earlier studies revealed that patients consider their functioning to be more limited than it is observed in performance-based testing. Second, despite the low maximal aerobic capacity of patients with CLBP,[8] they may experience no limitations in functioning when their present aerobic capacity is sufficient to perform their usual daily activities.[8 44] Research shows that, on average, patients with CLBP tend to reduce their physical activity. This could explain why participants in our study with lower maximal aerobic capacity do not necessarily report lower scores on self-reported functioning. This could be considered a 'deconditioning paradox': while present aerobic capacity may be lower than preexisting levels, the present level may still be sufficient for their current desired functioning. Because lifting capacity is a performance-based test and maximal lifting requires a certain amount of aerobic capacity, this might have contributed to the relationship observed in this study.

Strengths

The main strength of this study is that it is one of the first to apply a gold standard method to determine the maximal aerobic capacity in patients with CLBP and uses this direct measure to determine the relationship with functioning. It also replicates the results of a single other study using a similar approach,[11] thereby adding robustness to the results of both studies.

Limitations

The generalisability of the outcomes is limited due to the selection criteria applied in this study. Another limitation is that causal relationships between aerobic capacity and functioning cannot be made due to the cross-sectional study design. Further research is needed to unravel the relationship between maximal aerobic capacity and functioning. Similar studies should expand by means of performing multiple measurements spread across a longer period, preferably during a rehabilitation programme in which regular exercise is implemented. Additionally, a study with a prospective design would make it possible to estimate causal relationships. Because this study revealed no relations between maximal aerobic capacity and self-reported functioning, it does not justify aerobic capacity training during the rehabilitation programme as a standard treatment option for patients with CLBP. On the other hand, if (heavy) lifting is required, for example, for work, training to increase aerobic capacity, (temporarily) decreasing workload, or a combination of both may be considered as a treatment modality.

Future research should investigate whether patients who might benefit from increased maximal aerobic capacity have specific characteristics, such as high physical work demands or high-level leisure demands, enabling better personalised rehabilitation.

An unexpected 'side effect' of this study was that patients' informal responses after CPET were very positive, which we interpret as a sense of accomplishment, self-efficacy, and 'proof' of doing more than they had anticipated. However, this is non-systematically gathered data (anecdotal), for which future research is needed.

CONCLUSION

In conclusion, maximal aerobic capacity was significantly associated with lifting capacity but not with self-reported functioning. The absence of a relationship between maximal aerobic capacity and the self-reported functioning variables at group level should not be interpreted as that relationships do not exist at the level of the individual patient. Clinically, the aerobic capacity of the majority of patients will be sufficient to defy the functional demands of everyday functioning. However, individual patients' capacity may be lower than functionally required, and these patients' aerobic capacity will be a limiting factor to function normally. In these cases, aerobic capacity training and/or adaptations to match their functional demands should be considered to improve functioning.

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REFERENCES

1 O'Brien T, Breivik H. The impact of chronic pain-European patients' perspective over 12 months. *Scand J Pain* 2012;3:23–9.
2 Nicholas M, Vlaeyen JWS, Rief W, *et al*. The IASP classification of chronic pain for ICD-11: chronic primary pain. *Pain* 2019;160:28–37.
3 Gordon R, Bloxham S. A systematic review of the effects of exercise and physical activity on non-specific chronic low back pain. *Healthcare* 2016;4. doi:10.3390/healthcare4020022. [Epub ahead of print: 25 Apr 2016].
4 Vanti C, Andreatta S, Borghi S, *et al*. The effectiveness of walking versus exercise on pain and function in chronic low back pain: a systematic review and meta-analysis of randomized trials. *Disabil Rehabil* 2019;41:622–32.

5 Krismer M, van Tulder M, Low Back Pain Group of the Bone and Joint Health Strategies for Europe Project. Strategies for prevention and management of musculoskeletal conditions. low back pain (non-specific). *Best Pract Res Clin Rheumatol* 2007;21:77–91.
6 Verbrugghe J, Agten A, Stevens S, *et al*. Exercise intensity matters in chronic nonspecific low back pain rehabilitation. *Med Sci Sports Exerc* 2019;51:2434–42.
7 van Middelkoop M, Rubinstein SM, Verhagen AP, *et al*. Exercise therapy for chronic nonspecific low-back pain. *Best Pract Res Clin Rheumatol* 2010;24:193–204.
8 Smeets RJEM, Wittink H, Hidding A, *et al*. Do patients with chronic low back pain have a lower level of aerobic fitness than healthy controls?: are pain, disability, fear of injury, working status, or level of leisure time activity associated with the difference in aerobic fitness level? *Spine* 2006;31:90-7; discussion 98.
9 Duque I, Parra J-H, Duvallet A. Maximal aerobic power in patients with chronic low back pain: a comparison with healthy subjects. *Eur Spine J* 2011;20:87–93.
10 Verbunt JA, Seelen HA, Vlaeyen JW, *et al*. Fear of injury and physical deconditioning in patients with chronic low back pain. *Arch Phys Med Rehabil* 2003;84:1227–32.
11 McQuade KJ, Turner JA, Buchner DM. Physical fitness and chronic low back pain. An analysis of the relationships among fitness, functional limitations, and depression. *Clin Orthop Relat Res* 1988:198–204.
12 Wittink H, Takken T, de Groot J, *et al*. Assessing peak aerobic capacity in Dutch law enforcement officers. *Int J Occup Med Environ Health* 2015;28:519–31.
13 Jackson AS, Ross RM. Methods and limitations of assessing functional work capacity objectively. *J Back Musculoskelet Rehabil* 1996;6:265–76.
14 Hodselmans AP, Dijkstra PU, Geertzen JHB, *et al*. Exercise capacity in non-specific chronic low back pain patients: a lean body mass-based Astrand bicycle test; reliability, validity and feasibility. *J Occup Rehabil* 2008;18:282–9.
15 Tran D. Cardiopulmonary exercise testing. In: *Methods in molecular biology*. Springer, 2018.
16 Ansuategui Echeita J, Dekker R, Schiphorst Preuper HR, *et al*. Maximal cardiopulmonary exercise test in patients with chronic low back pain: feasibility, tolerance and relation with central sensitization. An observational study. *Disabil Rehabil* 2021:1–8.
17 Verbrugghe J, Agten A, Stevens S, *et al*. Disability, kinesiophobia, perceived stress, and pain are not associated with trunk muscle strength or aerobic capacity in chronic nonspecific low back pain. *Phys Ther Sport* 2020;43:77–83.
18 Berduszek RJ, Geerdink H, van der Sluis CK, *et al*. Health-Related physical fitness in patients with complaints of hand, wrist, forearm and elbow: an exploratory study. *BMJ Open Sport Exerc Med* 2021;7:e001148.
19 Ansuategui Echeita J, Schiphorst Preuper HR, Dekker R, *et al*. Central sensitisation and functioning in patients with chronic low back pain: protocol for a cross-sectional and cohort study. *BMJ Open* 2020;10:e031592.
20 World Medical Association. World Medical association Declaration of Helsinki: ethical principles for medical research involving human subjects. *JAMA* 2013;310:2191–4.
21 American Thoracic Society, American College of Chest Physicians. ATS/ACCP statement on cardiopulmonary exercise testing. *Am J Respir Crit Care Med* 2003;167:211–77.
22 Isernhagen SJ, Hart DL, Matheson LM. Reliability of independent observer judgments of level of lift effort in a kinesiophysical functional capacity evaluation. *Work* 1999;12:145–50.
23 Hart DL, Isernhagen SJ, Matheson LN. Guidelines for functional capacity evaluation of people with medical conditions. *J Orthop Sports Phys Ther* 1993;18:682–6.
24 Wasserman K, Hansen JE, Sue DY. Principles of testing and interpretation, 2012. Available: http://solution.lww.com/exercisetesting5e [Accessed 4 Jan 2022].
25 Albouaini K, Egred M, Alahmar A, *et al*. Cardiopulmonary exercise testing and its application. *Postgrad Med J* 2007;83:675–82.
26 Howley ET, Bassett DR, Welch HG. Criteria for maximal oxygen uptake: review and commentary. *Med Sci Sports Exerc* 1995;27:1292–301.
27 De Baets S, Calders P, Schalley N, *et al*. Updating the evidence on functional capacity evaluation methods: a systematic review. *J Occup Rehabil* 2018;28:418–28.
28 Brouwer S, Reneman MF, Dijkstra PU, *et al*. Test-Retest reliability of the Isernhagen work systems functional capacity evaluation in patients with chronic low back pain. *J Occup Rehabil* 2003;13:207–18.
29 Soer R, van der Schans CP, Geertzen JH, *et al*. Normative values for a functional capacity evaluation. *Arch Phys Med Rehabil* 2009;90:1785–94.
30 de Zwart BCH, Frings-Dresen MHW, van Duivenbooden JC. Test-Retest reliability of the work ability index questionnaire. *Occup Med* 2002;52:177–81.
31 Ahlstrom L, Grimby-Ekman A, Hagberg M, *et al*. The work ability index and single-item question: associations with sick leave, symptoms, and health--a prospective study of women on long-term sick leave. *Scand J Work Environ Health* 2010;36:404–12.
32 El Fassi M, Bocquet V, Majery N, *et al*. Work ability assessment in a worker population: comparison and determinants of work ability index and work ability score. *BMC Public Health* 2013;13:305.
33 Pijn Kennis Centrum academisch ziekenhuis Maastricht. Pain Disability Index - Dutch Language Version (PDI-DLV), 1999. Available: https://meetinstrumentenzorg.nl/instrumenten/pain-disability-index-dutch-language-version/ [Accessed 9 Jul 2020].
34 Soer R, Köke AJA, Vroomen PCAJ, *et al*. Extensive validation of the pain disability index in 3 groups of patients with musculoskeletal pain. *Spine* 2013;38:E562–8.
35 VanderZee KI, Sanderman R, Heyink JW, *et al*. Psychometric qualities of the Rand 36-Item health survey 1.0: a multidimensional measure of general health status. *Int J Behav Med* 1996;3:104–22.
36 Hawker GA, Mian S, Kendzerska T, *et al*. Measures of adult pain: visual analog scale for pain (vas pain), numeric rating scale for pain (NRS pain), McGill pain questionnaire (MPQ), short-form McGill pain questionnaire (SF-MPQ), chronic pain grade scale (CpGs), short Form-36 bodily pain scale (SF. *Arthritis Care Res* 2011;63:S240–52.
37 Crombez G, Vlaeyen J. Pain Catastrophizing Scale - Dutch Version (PCS-DV), 1996. Available: https://meetinstrumentenzorg.nl/instrumenten/pain-catastrophizing-scale/ [Accessed 9 Jul 2020].
38 van Wilgen CP, Nijs J, Don S. The injustice experience questionnaire: Nederlandstalige consensusvertaling, 2014. Available: http://www.paininmotion.be/storage/app/media//materials/IEQ-Dutch.pdf [Accessed 9 Jul 2020].
39 Derogatis LR. *BSI brief symptom inventory: Administration, Scoring, and Procedure Manual*. *4th ed*. APA PsycTests, 1993.
40 US. *Department of labor, employment and training administration*. 4th ed. Washington: Dictionary of occupational titles, 1991I.
41 Akoglu H. User's guide to correlation coefficients. *Turk J Emerg Med* 2018;18:91–3.
42 Brouwer S, Dijkstra PU, Stewart RE, *et al*. Comparing self-report, clinical examination and functional testing in the assessment of work-related limitations in patients with chronic low back pain. *Disabil Rehabil* 2005;27:999–1005.
43 Reneman MF, Jorritsma W, Schellekens JMH, *et al*. Concurrent validity of questionnaire and performance-based disability measurements in patients with chronic nonspecific low back pain. *J Occup Rehabil* 2002;12:119–29.
44 Orr LC, George SZ, Simon CB. Association between physical activity and pain processing in adults with chronic low back pain compared to pain-free controls. *J Back Musculoskelet Rehabil* 2017;30:575–81.