The Effectiveness of Technology-Supported Exercise Therapy for Low Back Pain

A Systematic Review

Thomas Matheve, MSc, Simon Brumagne, PhD, and Annick A.A. Timmermans, PhD

Abstract: Various technological systems have been developed to assist exercise therapy for low back pain. The aim of this systematic review was to provide an overview and to assess the effectiveness of the available technology-supported exercise therapy (TSET) programs for low back pain. The electronic databases Pubmed, Embase, Cochrane Central Register of Controlled Trials, PEDro, IEEE, and ACM were searched until January 2016. Randomized controlled trials (RCTs) using electronic technological systems simultaneously with exercise therapy for patients with low back pain were included. Twenty-five RCTs met the inclusion criteria. Seventeen studies involved patients with chronic low back pain, and electromyography biofeedback was the most prevalent type of technological support. This review shows that TSET seems to improve pain, disability, and quality of life for patients with low back pain, and that a standard treatment combined with an additional TSET program might be superior to a standard treatment alone. However, TSET seems not more effective compared to other interventions or a placebo intervention for improving these outcomes, which may partially be explained by the analytical approach of the current TSET-programs. For most technologies, only a limited number of RCTs are available, making it difficult to draw firm conclusions about the effectiveness of individual technological systems.

Key Words: Low Back Pain, Rehabilitation, Technology, Exercise Therapy

(*Am J Phys Med Rehabil* 2017;96:347–356)

Despite numerous treatment options, low back pain (LBP) remains an important health-related problem with a substantial impact on daily functioning. The lifetime prevalence of LBP is reported to be as high as 84%, whereas the estimated prevalence of chronic LBP (CLBP) is approximately 23%.[1] Furthermore, in the industrialized countries, CLBP is a leading cause of work absenteeism resulting in high economic and health care costs.[2]

Because of demographic changes, the prevalence of LBP is likely to increase in the future,[3,4] which in turn will contribute to the growing pressure on the health care system. The latter begs for innovative approaches that support both patients and therapists in their effort to obtain and offer high-quality rehabilitation. Up till now, exercise therapy is commonly used as the treatment of choice in the rehabilitation of LBP.[5] Despite the positive effects on pain and disability, not all patients benefit from this type of treatment, and the effect sizes (ESs) are only small to moderate.[6–8]

In the neurological field, rehabilitation technologies have been developed for 2 decades and have proven to yield improvement in patients with stroke.[9,10] Apart from the use of surface electromyography (sEMG) and real-time ultrasound imaging (RUSI), the interest in technologies that support exercise therapy for LBP has emerged only in recent years. Various systems are available that provide extrinsic feedback to enhance the accuracy of exercise performance. This seems logical, as patients with LBP often show an impaired internal feedback system, which leads to spinal control problems.[11] Currently, the feedback provided by physical therapists is usually based on palpation or inspection; however, the reliability of these assessments can vary considerably.[12–14] Therefore, it is thought that providing more accurate feedback by using technology could improve treatment outcomes.[15,16] Technology also aims to increase treatment adherence, which has been shown to be a predictor of treatment success of exercise programs for patients with CLBP.[17,18] This might be achieved by providing automated feedback messages based on objective information about the training frequency and intensity gathered by technological systems, as this has already been demonstrated for other health problems.[19,20] In addition, technological systems can offer a more stimulating setting for the patient to practice, such as virtual reality environments.[21]

Despite the recent development of electronic systems to support exercise therapy for LBP, a detailed overview of the effectiveness of the various technology-supported exercise therapy (TSET) programs is currently lacking. Therefore, the aims of this systematic review were to (1) inventory the available electronic technological systems supporting exercise

From the Rehabilitation Research Center (REVAL), Biomed, Faculty of Medicine and Life Sciences, Hasselt University, Diepenbeek, Belgium (TM, AAAT); and KU Leuven–University of Leuven, Department of Rehabilitation Sciences, Leuven, Belgium (SB).

All correspondence and requests for reprints should be addressed to: Thomas Matheve, MSc, Hasselt University, Agoralaan, Bldg A, 3590 Diepenbeek, Belgium.

Preliminary results were presented (poster presentation) at the 15th world congress of pain, October 6–11, 2014, Buenos Aires, Argentina, and at the 7th biennal congress of the Belgian Back Society, November 29, 2014, Ghent, Belgium.

Author contributions: The systematic search, screening of articles, data extraction, and risk of bias assessment was performed by T.M. and A.T. The draft was written by T.M., and A.T. and S.B. revised the manuscript for content and language. All authors discussed the results and commented on the manuscript.

Financial disclosure statements have been obtained, and no conflicts of interest have been reported by the authors or by any individuals in control of the content of this article.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.ajpmr.com).

Copyright © 2016 Wolters Kluwer Health, Inc. All rights reserved.

ISSN: 0894-9115

DOI: 10.1097/PHM.0000000000000615

Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.

therapy for LBP that have been evaluated in randomized controlled trials, and (2) assess the effectiveness of TSET for LBP, compared to other forms of rehabilitation, placebo interventions, or no treatment.

MATERIALS AND METHODS

Data Sources and Searches

This systematic review was conducted according to the preferred reporting items for systematic reviews and meta-analyses guidelines (see Supplemental Digital Content 1, http://links.lww.com/PHM/A323). A systematic search was performed up until January 2016 in the Pubmed, PEDro, EMBASE, Cochrane central register of controlled trials (CENTRAL), IEEE, and ACM databases. The following keywords (truncation indicated with an asterisk) were combined in various ways to identify relevant articles: LBP, (bio)feedback, internet, whole body vibration, electrical stimulation, ultrasonography (ultrasound), technology, robotics, telemedicine, virtual reality, smartphone, mobile app*, sensor(s), motor control, exercise therapy and stabilization exercise. A detailed search strategy can be found in Supplemental Digital Content 2 (http://links.lww.com/PHM/A324).

After removal of duplicates, 2 reviewers (T.M. and A.T.) independently screened the titles and abstracts of the obtained articles for eligibility. The relevant studies were read in full length to make a decision about the inclusion. Authors of papers were contacted for more information if this was necessary. The references of included articles and retrieved systematic reviews were screened for additional papers.

Study Selection

Study Design

Randomized controlled trials (RCTs) written in English or Dutch were included.

Subjects

Studies containing an adult population with (sub)acute or chronic LBP of musculoskeletal origin were included. LBP lasting less than 6 weeks was defined as acute LBP, between 6 and 12 weeks as subacute LBP, and more than 12 weeks as CLBP.[22] Trials including healthy subjects or patients with pelvic girdle pain, and studies on postoperative rehabilitation were excluded. If patients were described as having back pain, and no specific subanalysis was made for LBP, the article was excluded.

Outcomes

To be included, at least one of the following outcomes had to be reported: pain, disability, or quality of life.

Interventions

Studies had to compare TSET to other interventions, a placebo intervention, or no treatment. Any type of exercise therapy routinely used for the treatment of LBP was included, as long as it was supported by technology. This implies that the technology had to be used simultaneously with the exercise therapy. Because the development of current and future technologies mainly focuses on electronic systems (eg, sensors), only studies using technological devices with an electronic component were included. Purely mechanical systems, such as traditional fitness equipment, were not the scope of this review. Combined therapies were allowed as long as the independent effects of TSET could be assessed.[22] This implies that if a standard therapy was combined with an additional TSET intervention, the control group should have received the same standard intervention as the TSET group. For example, a study that compared physical therapy and TSET with physical therapy and stabilization exercises could be included in the review. If the control group would have received manipulative therapy and stabilization exercises, this study could not be included.

Data Extraction and Synthesis

The data extraction was performed independently by 2 reviewers (T.M. and A.T.) using a standardized form. The extracted data included the number of subjects, age, sex, duration of symptoms, technology-supported intervention, control intervention, outcomes (pain, disability, and quality of life), measurement times and follow-up times.

When possible, ESs (Hedges *g*) were calculated for between-groups differences. For this calculation, the sample sizes, and mean and standard deviation values from continuous data were extracted. If the required information could not be retrieved from the articles, authors were contacted to provide the missing data. Effect sizes were interpreted according to Cohen classification[23]: an ES of 0.2 was interpreted as small, 0.5 as medium, and 0.8 as large.

Results were described as postintervention, short-term (closest to 3 months' follow-up), intermediate term (closest to 6 months' follow-up) or long-term (closest to 1-year follow-up).[22]

Risk of Bias Assessment

The risk of bias was assessed using the checklist from the Cochrane Back Research Group, which consists out of 12 items.[22] Before evaluating the included articles, a risk of bias assessment tryout was conducted on similar articles. Positive scores were given on items that fulfilled the criteria, and negative scores were given if this was obviously not the case. If there was insufficient information, items were labeled unsure. Following the guidelines of the Cochrane Back Research Group, a study was categorized as having a low risk of bias if it had 6 or more positive items and no major flaws. Otherwise, the study was classified as having a high risk of bias. The assessment was done independently by 2 reviewers (T.M. and A.T.). If any disagreements persisted after discussion, a third reviewer would be contacted for consensus. No studies were excluded based on their risk of bias assessment.

RESULTS

Systematic Search

A sensitive search strategy was used and yielded 6195 records. After removal of duplicates and screening on title and abstract, 96 papers were withheld for full-text reading. Finally, 25 articles were included in this review. A flowchart of the selection process can be found in Figure 1.

© 2016 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.

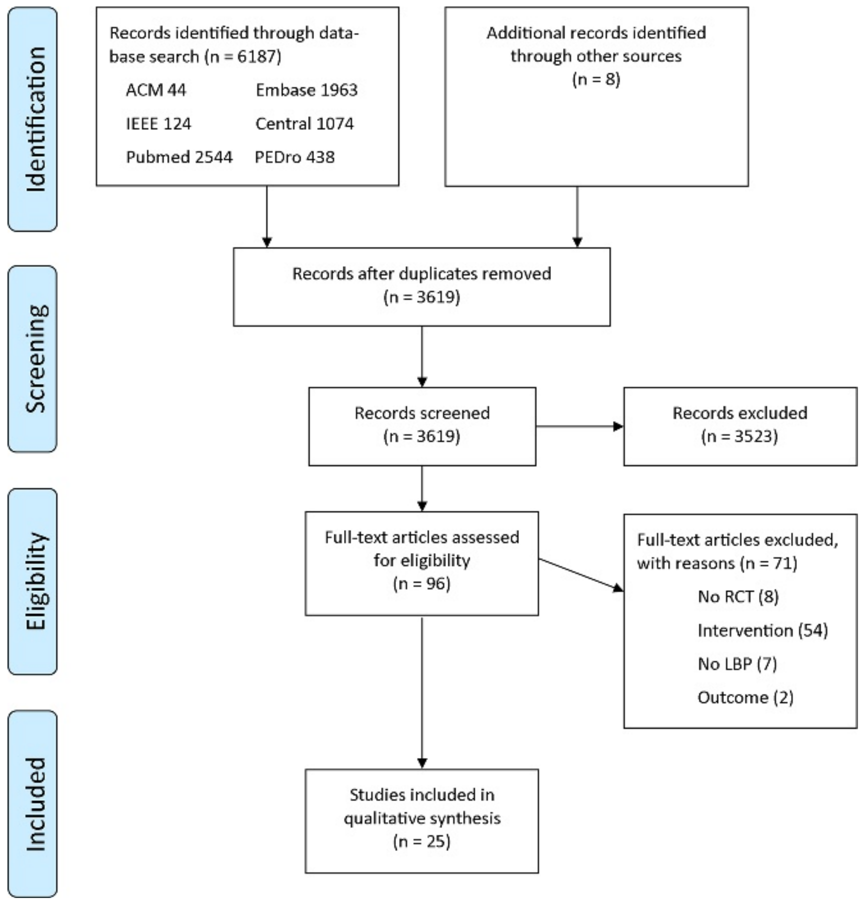

FIGURE 1. Preferred reporting items for systematic reviews and meta-analyses flowchart.

Risk of Bias

A high level of agreement was reached on the risk of bias assessment resulting in a kappa value of 86% (95% confidence interval, 0.81–0.91) across the items. Of the 25 included studies, 12 papers had a low risk of bias. Despite being described as RCTs, only 8 studies reported an adequate randomization process and a concealed allocation. Blinding of therapists and outcome assessors was adequate in only 4 papers, whereas blinding of participants was adequate in 5 papers. Details on the risk of bias assessment are presented in Table 1.

Inventory and Characteristics of TSET for LBP

Most of the studies (17/25) involved a CLBP population. Two studies used patients with acute LBP,[32,33] 2 studies from the same cohort used subjects with subacute LBP,[29,30] and 4 studies included patients with both (sub)acute and chronic LBP.[34,36,37,41] Ten different types of supportive technologies were described. Electromyography feedback (EMG-FB) was used in 9 papers, whereas for the other technologies, a maximum of 3 studies per technology was available. Table 2 provides an overview of the different TSET programs with comparisons. A detailed description of the study characteristics can be found in Supplemental Digital Content 3 (http://links.lww.com/PHM/A325).

Effectiveness of TSET

Pooling of data was considered inappropriate because of the substantial number of studies with a high risk of bias and because of clinical heterogeneity of the studies.[22] Therefore, no meta-analysis was performed, but effect sizes for individual studies are provided in Tables 3, 4, and 5. Positive ESs have to be interpreted in favor of the TSET intervention, whereas negative ESs favor the comparison (ie, other intervention, placebo, or waiting list).

Acute LBP

One study compared a standard EMG-FB program to individualized cognitive behavioral therapy (CBT), with both groups also receiving standard conservative care.[32] The EMG-FB group had significantly less improvement in pain posttreatment (ES, −0.86) and at intermediate term (ES, −0.40), but no differences were found for disability compared to the CBT group.

One study showed that the addition of RUSI-supported multifidus muscle training to standard medical care did not result in a greater reduction in pain and disability after treatment and at 6 weeks′ follow-up.[33] However, the TSET group experienced significantly less LBP recurrences during a 3-year follow-up period.[49]

© 2016 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.

TABLE 1. Risk of bias of included studies

Author, Year	Randomization Adequate	Concealed Allocation	Patient Blinding	Therapist Blinding	Outcome Assessor Blinded	Drop-out Rate	Intention to Treat	Selective Outcome Reporting	Baseline Equal	Co-Interventions	Compliance Rates	Timing of Outcome	Total
Ahmed et al., 2013[24]	?	?	-	-	-	-	?	+	?	+	?	+	3
Asfour et al., 1990[25]	?	?	-	-	?	?	?	+	+	+	?	+	4
Bush et al., 1985[26]	?	?	+	-	-	-	-	+	+	?	?	+	4
de Souza et al., 2009[27]	?	?	+	-	-	+	?	+	+	?	+	+	6
del-Pozo Cruz et al., 2011[28]	+	?	-	-	-	+	-	+	+	?	+	+	6
del-Pozo Cruz et al., 2012[29]	+	+	-	+	-	+	+	+	+	?	+	+	9
del-Pozo Cruz et al., 2013[30]	+	+	-	+	-	+	-	+	+	?	+	+	8
Donaldson et al., 1994[31]	?	?	-	-	-	+	?	+	+	+	?	+	5
Hasenbring et al., 1999[32]	-	-	-	-	-	-	-	+	+	-	?	+	3
Hides et al., 1996[33]	+	+	-	-	-	+	-	+	+	?	+	+	7
Hügli et al., 2015[34]	+	+	-	-	-	+	+	+	+	+	+	+	9
Kapitza et al., 2010[35]	+	+	+	+	+	+	+	+	+	?	?	+	10
Kent et al., 2015[36]	+	-	+	-	+	+	+	+	+	?	+	+	9
Kim et al., 2014[37]	?	?	-	-	-	?	?	+	?	+	?	?	2
Krein et al., 2013[38]	+	+	-	?	+	+	+	+	+	?	-	+	8
Magnusson et al., 2008[39]	?	?	-	-	-	-	?	-	+	?	?	+	2
Massé-Alarie et al., 2013[40]	?	?	+	+	+	?	?	+	+	?	+	+	7
Miller et al., 2004[41]	+	+	-	-	-	-	?	+	?	?	?	+	4
Newton-John et al., 1995[42]	-	-	-	-	-	-	-	+	+	?	?	+	3
Nouwen, 1983[43]	?	?	+	-	-	+	+	+	-	?	+	+	6
Park et al., 2013[44]	?	?	-	-	-	+	+	-	+	+	?	+	5
Rittweger et al., 2002[45]	?	?	-	?	-	+	-	+	+	+	?	+	5
Stuckey et al., 1986[46]	?	?	-	-	-	+	-	+	+	+	?	+	5
Unsgaard-Tøndel et al., 2010[47]	+	+	-	-	-	+	+	+	+	?	+	+	8
Yang and Seo, 2015[48]	?	?	-	-	-	+	+	+	+	?	?	+	5

+, criterion fulfilled; -, criterion not fulfilled; ?, unclear whether criterion is fulfilled.

© 2016 Wolters Kluwer Health, Inc. All rights reserved.
Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.

TABLE 2. Summary of TSET programs and their comparisons

TSET	Comparison
Surface EMG-FB for increasing/decreasing paravertebral muscle activity (n = 6)	Waiting list (n = 3),[26,42,43] placebo (n = 2),[26,46] relaxation exercises (n = 2),[31,46] CBT (n = 2),[32,42] education (n = 1),[31] usual care (n = 1)[32]
Surface EMG-FB for strengthening or stabilization exercises (n = 3)	Standard physical therapy (n = 1),[25] exercises without feedback (n = 1),[24] waiting list (n = 1)[27]
RUSI for transversus abdominis muscle training (n = 1)	Sling exercises (n = 1),[47] general exercises (n = 1)[47]
RUSI for multifidus muscle training (n = 1)	Medical management (n = 1)[33]
Internet mediated exercise interventions (n = 3)	Exercises without online support (n = 1),[38] access to website containing ergonomic advice (n = 2)[29,30]
Nintendo Wii (n = 2)	Physical therapy and trunk stabilization exercises (n = 2),[37,44] physical therapy (n = 1)[44]
Whole-body vibration (n = 3)	Strengthening exercises (n = 1),[45] standard medical care (n = 1),[28] stabilization exercises (n = 1)[48]
Postural feedback (n = 3)	Back school (n = 1),[39] stabilization exercises (n = 1),[34] guideline-based physical therapy (n = 1)[36]
Respiratory feedback (n = 1)	Placebo respiratory feedback (n = 1)[35]
Peripheral magnetic stimulation (n = 1)	Sham stimulation (n = 1)[40]
Video instructions (n = 1)	Exercises without video instructions (n = 1)[41]

CBT, cognitive behavioral therapy; EMG, electromyography; RUSI, real-time ultrasound imaging; TSET, technology supported exercise therapy.

Subacute LBP

Two studies from the same cohort of office workers assessed the effects of adding a Web-based exercise program to standard preventive occupational care.[29,30] Disability (ES, 1.61) and quality of life significantly improved after the intervention in the TSET group, but not in the control group, and a significant between-groups difference was present.

Chronic LBP

Standard Treatment and TSET Versus Standard Treatment Alone

Three of 4 studies showed beneficial effects on pain when a TSET-program was added to a standard treatment (ES range, 0.38–0.75).[28,39,48] The 2 studies reporting quality of life[28,39] showed better results for the TSET group (ES, 0.38) and mixed results were reported for disability in 2 studies (ES range, 0.06–0.27).[28,48] The positive effects were found in studies with an additional whole-body vibration intervention[28,48] or a motor learning program with postural feedback.[39] Adding lumbar extensor strengthening exercises with EMG-FB to a 2-week physical therapy program did not result in a greater reduction in pain.[25]

TSET Versus Other Interventions

Eight studies compared TSET to other interventions.[24,31,38,42,44–47] Technology-supported exercise therapy reduced pain significantly more than other interventions in 2 studies,[24,38] 5 studies found no differences,[31,38,42,45,47] and in one paper, TSET was less effective.[46] Concerning disability, 4 studies showed no differences,[38,42,45,47] and in one paper, TSET was less effective.[46] No differences in quality of life were found in one study.[38]

In 4 studies, patients were asked to increase or decrease muscle activity from the paravertebral extensors, while they were provided with EMG-FB from these muscles. No differences were found between EMG-FB and education[31] or CBT[42] for pain or disability. Compared to relaxation exercises, EMG-FB was less effective for reducing disability,[46] and mixed results were shown for pain reduction.[31,46]

Trunk stabilization exercises with EMG-FB resulted in a significantly greater improvement in pain than trunk stabilization exercises without technological support (ES, 0.91).[24] In contrast, no differences in the reduction of pain and disability were found between whole-body vibration and strengthening exercises,[45] between transversus abdominis muscle training with RUSI and sling exercises or general strengthening,[47] and between an Internet-mediated walking program and a standard walking program.[38] The latter study also reported no between-groups differences in quality of life.

In 3 studies, the technological support was the single difference between the experimental and control interventions.[24,38,46] In one paper, the TSET intervention led to a greater reduction in pain,[24] one trial found no differences,[38] and TSET was less effective in another study.[46]

TSET Versus Placebo or Waiting List

Six of 7 studies reporting pain as an outcome found no differences between TSET and a placebo[26,35,40,46] or a waiting list,[26,27,43] whereas 4 of 5 studies showed no differences in disability.[27,35,40,46] In one study, the TSET group improved significantly more on both outcomes.[42]

Four studies used paravertebral muscle control exercises with EMG-FB as technological support. The EMG-FB exercises led to a greater reduction in pain and disability than a waiting list control group at posttreatment evaluation (ES range, 0.85–1.19), but not at intermediate term in one study.[42] No significant between-groups differences in pain[26,43,46] or disability[46] were found in the other studies.

For both pain and disability, strengthening exercises with EMG-FB,[27] breathing exercises with respiratory FB,[35] and a single session of transversus abdominis muscle training with repetitive peripheral magnetic stimulation[40] were not more effective than a waiting list,[27] or a placebo (sham) intervention.[35,40]

Mixed Population

Three studies compared TSET to another intervention and included patients with both (sub)acute and chronic LBP. A TSET program containing Wii-fit exercises led to greater reductions in pain and disability than physical therapy in one

© 2016 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.

TABLE 3. Effect sizes of studies comparing a standard therapy and TSET to a standard therapy alone

Study	TSET	Comparison	Outcome	Hedges *g*	*P*
Acute low back pain					
Hides et al., 1996[33]	Standard medical care + multifidus muscle training with RUSI. TSET: 8 sessions, 2×/wk	Standard medical care	Pain (VAS)	-	NS
			Pain (MPQ)	-	NS
			Disability (RMQ)	-	NS
Subacute low back pain					
Del-Pozo Cruz et al., 2012,[29] 2013[30]	Standard preventative occupational care + internet mediated exercises. TSET: 9 months of unsupervised daily exercises	Standard preventative occupational care	Disability (RMQ)[29]	1.61	<0.01
			Disability (ODI)[30]	-	0.001
			QoL (EQ-5D-3 L)[30]	-	<0.001[b]
Chronic low back pain					
Asfour et al., 1990[25]	Physical therapy + trunk extensor strengthening with EMG-FB. 2 wk ST + 8 sessions TSET, 4×/wk	Physical therapy. 2 wks	Pain (VAS)	0.34	NS
Del-Pozo Cruz et al., 2011[28]	Standard medical care + WBV-training. TSET: 24 sessions, 2×/wk	Standard medical care	Pain (VAS)	0.76	0.006
			Disability (RMQ)	0.27	0.001
			Disability (ODI)	0.66	0.013
			QoL (EQ-5D-3 L)	0.38	0.042
Magnusson et al., 2008[39]	Standard rehabilitation + motor learning program with postural FB. 5 sessions ST, 1×/wk + 10 sessions of TSET, 2×/wk	Standard rehabilitation. 5 sessions, 1×/wk	Pain (VAS)	-	<0.001
			Pain (VAS)[a]	-	<0.05
			QoL (SF-36)	-	<0.05[b]
			QoL (SF-36)[a]	-	<0.05
Park et al., 2013[44]	Physical therapy + Wii sports. 24 sessions, 3×/wk	Physical therapy. 24 sessions, 3×/wk	Pain (VAS)	−0.11	NR
			QoL (RAND-36)	0.18	NR
Yang et al., 2015[48]	Stabilization exercises + WBV-exercises. 18 sessions, 3×/wk	Stabilization exercises. 18 sessions, 3×/wk	Pain (VAS)	0.75	<0.05
			Disability (ODI)	0.06	NS
Mixed population					
Kent et al., 2015[36]	Guideline-based physical therapy + motor control exercises with postural FB. 6–8 sessions in 10 wks	Guideline-based physical therapy. 6–8 sessions in 10 wks	Pain (QVAS)	1.27	<0.05
			Disability (RMQ)	1.74	<0.05
			Disability (PSFS)	1.87	<0.05

All results are postintervention, unless otherwise reported. Positive ESs are in favor of the TSET group. When it was not possible to calculate an ES, this is indicated with a hyphen (-). For *P* values: All values are for between-groups comparisons.

[a]Intermediate term. [b]For most of the subscales of the questionnaire.

ADL, activities of daily life; EQ-5D-3EL, European quality of life, 5 dimensions, 3 levels; MPQ, McGill pain questionnaire; NS, nonsignificant; NR, not reported; ODI, Oswestry Disability Index; PSFS, Patient-Specific Functioning Scale; QoL, quality of life; QVAS, Quadruple Visual Analog Scale; RAND-36, RAND-36 Health Status Inventory; RMQ, Roland Morris Disability Questionnaire; ST, standard therapy; VAS, Visual Analog Scale.

study (ES range, 0.88–1.47).[37] Two studies comparing a conventional exercise program with exercises supported by postural feedback[34] or video instructions[41] showed no between-groups differences in disability[34,41] and most aspects of quality of life.[41] The addition of motor control exercises supported by postural feedback to guideline-based physical therapy led to greater improvements in pain (ES, 1.27) and disability (ES range, 1.74–1.87) than guideline-based physical therapy alone.[36]

No differences in disability[34,41] and quality of life[41] were found in 2 studies, where the technological support was the single difference between the interventions.

DISCUSSION

The aims of this review were to give an overview and to assess the effectiveness of the available TSET programs for patients with LBP. Twenty-five RCTs were included that compared TSET to other forms of rehabilitation, a placebo intervention, or no treatment. Electromyography FB was used to support exercise therapy in 9 papers, whereas few studies were available for the other technologies.

With regard to effectiveness, the results of this review show that TSET seems to improve pain, disability, and quality of life in patients with subacute and chronic LBP, but seems not to provide beneficial effects for patients with acute LBP. When a TSET program was added to a standard treatment, this was superior to a standard treatment alone. In most cases, however, TSET did not yield better results compared to other interventions or a placebo intervention (sham FB). Furthermore, when the technological support was the single difference between interventions, no between-groups differences could be found. One explanation for the lack of additional benefit from technological support might be that these TSET programs mostly adopted a narrow approach to exercise therapy, that is, training of one particular function of a specific muscle or muscle group. For example, 4 of 7 studies comparing TSET to a placebo intervention used sEMG-FB to control paravertebral muscle activity, and one study used a single session of transversus abdominis

 © 2016 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.

TABLE 4. Effect sizes of studies comparing TSET to other interventions

Study	TSET	Comparison	Outcome	Hedges *g*	*P*
Acute LBP					
Hasenbring et al., 1999[32]	Standard physiotherapy + PVM control exercises with EMG-FB. 12 sessions, 1×/wk	Standard physiotherapy + Cognitive behavioral therapy. 10–40 sessions (mean = 27)	Pain (VAS)	−0.86	<0.05[b]
			Pain (VAS)[a]	−0.40	<0.05[b]
			Disability (ADL-Q)	−0.30	NS
			Disability (ADL-Q)[a]	−0.20	NS
Chronic LBP					
Ahmed et al., 2013[24]	Stabilization exercises with EMG-FB. 12 sessions, 2×/wk	Stabilization exercises without EMG-FB. 12 sessions, 2×/wk	Pain (VAS)	0.89	0.027
Donaldson et al., 1994[31]	PVM control exercises with EMG-FB. 10 sessions	Relaxation exercises. 10 sessions	Pain (VAS)	0.42	NS
			Pain (MPQ)	0.82	<0.05
		Education. 10 sessions	Pain (VAS)	0.68	NS
			Pain (MPQ)	0.78	NS
Krein et al., 2013[38]	Walking program with internet support. 12-month intervention	Walking program without internet support. 12-month intervention	Pain (VAS)	0.09	NS
			Disability (RMQ)	0.29	NS
			QoL (SF-36)	−0.20	NS
Newton-John et al., 1995[42]	Paravertebral muscle control exercises with EMG-FB. 8 sessions, 2×/wk	Cognitive behavioral therapy. 8 sessions, 2×/wk	Pain (NPRS)	0.20	NS
			Disability (PDI)	0.23	NS
			Disability (PDI)[a]	0.35	NS
Park et al., 2013[44]	Physical therapy + Wii sports. 24 sessions, 3×/wk	Physical therapy + stabilization exercises. 24 sessions, 3×/wk	Pain (VAS)	−0.91	NR
			QoL (RAND-36)	−0.43	NR
Rittweger et al., 2002[45]	Whole-body vibration. 18 sessions in 12 wks	Strengthening exercises. 18 sessions in 12 wks	Pain (VAS)	−0.11	NS
			Disability (PDI)	−0.09	NS
			Disability (PDI)[a]	−0.21	NS
Stuckey et al., 1986[46]	PVM control exercises with EMG-FB. 8 sessions	Relaxation exercises. 8 sessions	Pain (VAS)	−0.2	<0.04[b]
			Disability (ADL-Q)	−0.46	<0.03[b]
Unsgaard-Tøndel et al., 2010[47]	TrA exercises with RUSI. 8 sessions, 1×/wk	Sling exercises. 8 sessions, 1×/wk	Pain (NPRS)	0.3	NS
			Disability (ODI)	0.36	NS
		General exercises. 8 sessions, 1×/wk	Pain (NPRS)	0.49	NS
			Disability (ODI)	0.56	NS
Mixed population					
Hügli et al., 2015[34]	Motor control exercises with postural FB. 9 sessions	Motor control exercises without postural FB. 9 sessions.	Disability (ODI)	-	NS
			Disability (PSFS)	-	NS
Kim et al., 2014[37]	Wii fit yoga. 12 sessions, 3×/wk	Physical therapy and trunk stabilization. No info on number of treatments	Pain (VAS)	1.47	<0.01
			Disability (RMQ)	0.88	<0.05
			Disability (ODI)	1.11	<0.05
Miller et al., 2004[41]	Exercises with video instructions. ±4 sessions in 4–6 wk	Exercises with face-to-face instructions. ±4 sessions in 4–6 wk	Disability (RMQ)	0.18	NS
			QoL (SF-36)	-	NS[c]

All results are postintervention, unless otherwise reported. Positive ESs are in favor of the TSET group. For *P* values: All values are for between-groups comparisons.

[a]Intermediate term. [b]Significant in favor of the control group. [c]For most subscales of the questionnaire.

ADL-Q, activities of daily life questionnaire; MPQ, McGill pain questionnaire; NPRS, Numeric Pain Rating Scale; NR, not reported; NS, nonsignificant; ODI, Oswestry Disability Index; PDI, Pain Disability Index; PSFS, Patient-Specific Functioning Scale; PVM, paravertebral muscle; QoL, quality of life; RAND-36, RAND-36 Health Status Inventory; RMQ, Roland Morris Disability Questionnaire; SF-36, Short form-36; TrA, transversus abdominis muscle; VAS, Visual Analog Scale.

muscle training. Although alterations in paravertebral sEMG[50] and transversus abdominis muscle function[51,52] have been reported in patients with CLBP, it may be questioned whether these minimal interventions are sufficient to improve complex problems such as CLBP.

There is growing consensus that exercise therapy for LBP should be tailored to the patient's specific needs.[53–55] This implies that functional exercises, relevant for the individual patient, have to be integrated in the rehabilitation process. Only one RCT[36] could be retrieved that incorporated technology into this functional approach, and therefore, the implementation of technological systems into functional movements or activities poses an important challenge. In this respect, O'Sullivan et al.[56] showed that patients with sitting-related CLBP experienced less pain when they received real-time postural feedback while watching a DVD, which was associated with an altered sitting behavior. In an attempt to reduce flexion postures and movements, Ribeiro et al.[57] investigated the effects of a wearable posture-monitor providing feedback on spinal flexion positions during daily life.

© 2016 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.

TABLE 5. Effect sizes of studies comparing TSET to placebo or a waiting list

Study	TSET	Comparison	Outcome	Hedges *g*	*P*
Chronic low back pain					
Bush et al., 1985[26]	PVM control exercises with EMG-FB. 8 sessions	Placebo-FB. 8 sessions	Pain (VAS)	-	NS
			Pain (VAS)[a]	-	NS
			Pain (MPQ)	-	NS
			Pain (MPQ)[a]	-	NS
		Waiting list	Pain (VAS)	-	NS
			Pain (VAS)[a]	-	NS
			Pain (MPQ)	-	NS
			Pain (MPQ)[a]	-	NS
De Sousa et al., 2009[27]	Abdominal strengthening with EMG-FB. 16 sessions, 2×/wk	Waiting list	Pain (VAS)	0.53	NS
			Disability (RMQ)	0.47	NS
Kapitza et al., 2010[35]	Breathing exercises with respiratory FB. 15 days of home exercises	Breathing exercises with sham respiratory FB. 15 days of home exercises	Pain (VAS)	−0.31	NS
			Disability (PDI)	0.03	NS
Massé-Alarie et al., 2013[40]	TrA training with RPMS. 1 session	TrA training with sham RPMS. 1 session	Pain (VAS)	-	NS
			Disability (QBPDS)	-	NS
Newton-John et al., 1995[42]	PVM control exercises with EMG-FB. 8 sessions, 2×/wk	Waiting list	Pain (NPRS)	1.19	<0.007
			Disability (PDI)	0.85	<0.003
Nouwen et al., 1983[43]	PVM control exercises with EMG-FB. 15 sessions, 5×/wk	Waiting list	Pain (5-point scale)	0.36	NS
Stuckey et al., 1986[46]	PVM control exercises with EMG-FB. 8 sessions	Placebo-FB. 8 sessions	Pain (VAS)	0.79	NS
			Disability (ADL-Q)	−0.16	NS

All results are postintervention, unless otherwise reported. Positive ESs are in favor of the TSET group. When it was not possible to calculate an ES, this is indicated with a hyphen (-). For *P* values: All values are for between-groups comparisons, NS.

[a]Intermediate term.

ADL, activities of daily life; MPQ, McGill pain questionnaire; NPRS, Numeric Pain Rating Scale; NS, nonsignificant; PDI, Pain Disability Questionnaire; PVM, paravertebral muscle; QBPDS, Quebec Back Pain Disability Index; RMQ, Roland Morris Disability Questionnaire; RPMS, repetitive peripheral magnetic stimulation; TrA, transversus abdominis muscle; VAS, Visual Analog Scale.

Subjects receiving constant feedback significantly reduced spinal flexion after a 4-week intervention period. Therefore, although there is evidence that real-time postural feedback from technological systems can improve spinal posture and reduce aggravating movements during daily life, its long-term benefit on pain and disability needs further investigation.

The combination of a standard treatment with a TSET program was superior to a standard treatment alone. This is in line with other research showing that a multimodal intervention leads to better outcomes than a unimodal intervention for patients with CLBP.[58] However, it should be noted that in 5 of 8 studies, the standard treatment alone did not lead to significant improvements.[25,28–30,36] Adding a TSET program to these ineffective treatments clearly improved pain (ES range, 0.27–1.87) and disability (ES range, 0.76–1.27).[28–30,36] The additional benefits of a TSET program were less obvious when the standard treatment alone was already effective (ES_{pain}, 0.76; $ES_{disability}$, 0.06).[33,39,48] These results highlight the importance of including a form of (technology-supported) exercise therapy in the rehabilitation of patients with LBP. The supplementary effects might be more pronounced in patients who did not improve by means of their previous treatment but are more likely to depend on the patient population and the content of both the (technology supported) exercise therapy and the standard rehabilitation. Indeed, some patients may not respond well to exercise therapy,[59] and might be better off with other types of treatment.[60]

Because the available technologies have changed over the years, it might be argued that interventions using more recently developed systems could result in better outcomes. Seven of 10 studies that were published before 2005 used EMG-FB as technological support,[25,26,31,32,42,43,46] whereas only 2 studies investigated the effects of EMG-FB in the past decade.[24,27] This suggests that a greater variety of technologies is currently available but may also result from the lack of effectiveness of TSET programs using EMG-FB.[25–27,32,42,43,46] Looking at the more recent trials, 2 smaller studies (n = 60) with a high risk of bias showed that TSET was more effective than other treatments,[24,37] whereas 4 studies (n = 743), 3 with a low risk of bias, indicated that there was no difference between interventions.[34,38,41,47] Therefore, our overall conclusion remains that TSET is not more effective than other treatments, also when only recent studies are considered.

Future Directions

The rehabilitation of CLBP is a long process often involving a home exercise program. The problem is that up to 50% to 70% of patients with CLBP do not adhere to home exercise prescriptions.[61,62] Improving these numbers seems warranted because the level of adherence has been reported to be a predictor of treatment success for patients with CLBP.[18,63] The use of technological applications that support therapy at home may

© 2016 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.

offer an additional value for promoting adherence, as research in other patient populations has shown.[19,20] However, only 5 of the included studies provided patients with technological support in the home situation,[34–36,38,41] and only 2 of these studies reported data on adherence to home exercises.[34,38] Hügli et al.[34] showed that there was no difference in time spent on home exercises between subjects who practiced in a game environment and subjects who performed conventional exercises. Krein et al.[38] compared 2 pedometer-supported walking programs, where one group had also access to a specific Website and received automated feedback messages on walking goals. Only 20% to 25% of patients logged in to the Website or uploaded pedometer data for more than 80% of recommended times, and this online support did not result in a significant increase in daily walking distance. These results suggest that simply providing patients with LBP with technological support at home does not automatically lead to an improved adherence. Consequently, specific interventions are probably needed.[64]

Treatment effects might also be enhanced by offering reliable feedback on the quality of exercise performance by using technology.[15,16] Patients with CLBP often display altered movement patterns at the spine,[65] making the evaluation and correction of these patterns key components in the rehabilitation.[53] Besides clinical judgment by a therapist,[66] movement patterns can be assessed with kinematic measurements.[67,68] However, the feasibility of kinematic assessment and feedback provision during exercises, especially in the home environment, is limited because of several reasons. Most of the kinematic assessment tools are complex, require a standardized setup, and are used in laboratory situations. More simple devices have been developed to address these disadvantages, but they may not be suited for precise kinematic assessment during 3-dimensional movements.[69] Of course, it can be argued how precise feedback needs to be in a clinical setting. Rather than constantly keeping a fixed neutral lordosis in the lumbar spine, patients should prevent excessive end-range movements and postures.[53] Preliminary results show that the latter can be achieved for movements in the sagittal plane by feedback from portable technological devices.[56,57] Therefore, we believe that these types of technological systems are worthwhile pursuing further.

Study Limitations

Because the field of rehabilitation technology is rapidly changing and we only included RCTs, this review does not provide an exhaustive overview of the available technological systems that support exercise therapy for patients with LBP. Furthermore, 68% of the studies used a CLBP population, and besides EMG-FB, a limited number of studies per technology could be retrieved. This makes it difficult to draw firm conclusions on the effectiveness of the technologies other than EMG-FB, and on the effects of TSET on (sub)acute LBP. Only 5 studies were found where the technological support was the single difference between the TSET and control intervention. This means that in most of the studies, the TSET program was compared to a different exercise program or a nonexercise intervention. Consequently, the results on the additional effects of the technological support itself could only be based on few studies. Finally, approximately half of the studies had a high risk of bias, and an adequate power calculation was lacking in most of the papers, limiting the strength of our conclusions.

CONCLUSIONS

The additional benefit from technological support on pain, disability, and quality of life is limited, also when only recently published trials are considered. Only the addition of a complementary TSET program to a standard treatment resulted in significantly greater improvements on these outcomes. The lack of supplementary effectiveness of technological systems may partly be explained by the fact that the current technologies are mostly used during analytical exercises and are not introduced into functional rehabilitation or in the home environment.

REFERENCES

1. Airaksinen O, Brox JI, Cedraschi C, et al: Chapter 4. European guidelines for the management of chronic nonspecific low back pain. *Eur Spine J* 2006;15:S192–300
2. Dagenais S, Caro J, Haldeman S: A systematic review of low back pain cost of illness studies in the United States and internationally. *Spine J* 2008;8:8–20
3. Hoy D, Bain C, Williams G, et al: A systematic review of the global prevalence of low back pain. *Arthritis Rheum* 2012;64:2028–37
4. Shiri R, Karppinen J, Leino-Arjas P, et al: The association between obesity and low back pain: a meta-analysis. Am J Epidemiol 2010;15:135–54
5. 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
6. Balagué F, Mannion AF, Pellisé F, et al: Non-specific low back pain. *Lancet* 2012;379:482–91
7. Byström MG, Rasmussen-Barr E, Grooten WJ: Motor control exercises reduces pain and disability in chronic and recurrent low back pain: a meta-analysis. *Spine* 2013;38:E350–8
8. Hayden JA, van Tulder MW, Malmivaara A, et al: Exercise therapy for treatment of non-specific low back pain. *Cochrane Database Syst Rev* 2005;3:CD000335
9. Farmer SE, Durairaj V, Swain I, et al: Assistive technologies: can they contribute to rehabilitation of the upper limb after stroke? *Arch Phys Med Rehabil* 2014;95:968–85
10. Mehrholz J, Hädrich A, Platz T, et al: Electromechanical and robot-assisted arm training for improving generic activities of daily living, arm function, and arm muscle strength after stroke. *Cochrane Database Syst Rev* 2012;6:CD006876
11. Brumagne S, Dolan P, Pickar JG: What is the relation between proprioception and low back pain? in Hodges P, Cholewicki J, van Dieën J (eds): *Spinal Control: The Rehabilitation of Back Pain*. London, United Kingdom, Churchill Livingstone, 2013, 219–30
12. Carlsson H, Rasmussen-Barr E: Clinical screening tests for assessing movement control in non-specific low-back pain. A systematic review of intra- and inter-observer reliability studies. *Man Ther* 2013;18:103–10
13. Costa LO, Costa Lda C, Cançado RL, et al: Short report: intra-tester reliability of two clinical tests of transversus abdominis muscle recruitment. *Physiother Res Int* 2006;11:48–50
14. Haneline MT, Cooperstein R, Young M, et al: Spinal motion palpation: a comparison of studies that assessed intersegmental end feel vs excursion. *J Manipulative Physiol Ther* 2008;31:616–26
15. Giggins OM, Persson UM, Caulfield B: Biofeedback in rehabilitation. *J Neuroeng Rehabil* 2013;10:60
16. Hides JA, Richardson CA, Jull GA: Use of real-time ultrasound imaging for feedback in rehabilitation. *Man Ther* 1998;3:125–31
17. Hicks GE, Benvenuti F, Fiaschi V, et al: Adherence to a community-based exercise program is a strong predictor of improved back pain status in older adults: an observational study. *Clin J Pain* 2012;28:195–203
18. Mannion AF, Helbling D, Pulkovski N, et al: Spinal segmental stabilisation exercises for chronic low back pain: programme adherence and its influence on clinical outcome. *Eur Spine J* 2009;18:1881–91
19. Marios T, Dalton S, Smart NA: The effect of tele-monitoring on exercise training adherence, functional capacity, quality of life and glycemic control in patients with type II diabetes. *J Sports Sci Med* 2012;11:51–6
20. Watson A, Bickmore T, Cange A, et al: An internet-based virtual coach to promote physical activity adherence in overweight adults: randomized controlled trial. *J Med Internet Res* 2012;14:e1
21. Jansen-Kosterink SM, Huis In 't Veld RM, Schönauer C, et al: A serious exergame for patients suffering from chronic musculoskeletal back and neck pain: a pilot study. *Games Health J* 2013;2:299–307
22. Furlan AD, Pennick V, Bombardier C, et al: 2009 Updated method guidelines for systematic reviews in the Cochrane Back Review Group. *Spine* 2009;34:1929–41
23. Cohen J: *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed. Hillsdale, Lawrence Erlbaum, 1988
24. Ahmed H, Iqbal A, Shaphe MA: Efficacy of electromyography biofeedback training on trunk stability in chronic low back pain. *Indian J Physiother Occup Ther* 2013;7:81–6

© 2016 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.

25. Asfour SS, Khalil TM, Waly SM, et al: Biofeedback in back muscle strengthening. *Spine* 1990;15:510–3
26. Bush C, Ditto B, Feuerstein M: A controlled evaluation of paraspinal EMG biofeedback in the treatment of chronic low back pain. *Health Psychol* 1985;4:307–21
27. de Sousa KSD, Orfale AG, Meireles SM, et al: Assessment of a biofeedback program to treat chronic low back pain. *J Musculoskelet Pain* 2009;17:369–77
28. del Pozo-Cruz B, Hernández Mocholí MA, Adsuar JC, et al: Effects of whole body vibration therapy on main outcome measures for chronic non-specific low back pain: a single-blind randomized controlled trial. *J Rehabil Med* 2011;43:689–94
29. del Pozo-Cruz B, Adsuar JC, Parraca J, et al: A web-based intervention to improve and prevent low back pain among office workers: a randomized controlled trial. *J Orthop Sports Phys Ther* 2012;42:831–41
30. del Pozo-Cruz B, Gusi N, del Pozo-Cruz J, et al: Clinical effects of a nine-month web-based intervention in subacute non-specific low back pain patients: a randomized controlled trial. *Clin Rehabil* 2013;27:28–39
31. Donaldson S, Romney D, Donaldson M, et al: Randomized study of the application of single motor unit biofeedback training to chronic low back pain. *J Occup Rehabil* 1994;4:23–37
32. Hasenbring M, Ulrich HW, Hartmann M, et al: The efficacy of a risk factor-based cognitive behavioral intervention and electromyographic biofeedback in patients with acute sciatic pain. An attempt to prevent chronicity. *Spine* 1999;24:2525–35
33. Hides JA, Richardson CA, Jull GA: Multifidus muscle recovery is not automatic after resolution of acute, first-episode low back pain. *Spine* 1996;21:2763–9
34. Hügli AS, Ernst MJ, Kool J, et al: Adherence to home exercises in non-specific low back pain. A randomised controlled pilot trial. *Journal of Bodywork and Movement Therapies* 2015;19:177–85
35. Kapitza KP, Passie T, Bernateck M, et al: First non-contingent respiratory biofeedback placebo versus contingent biofeedback in patients with chronic low back pain: a randomized, controlled, double-blind trial. *Appl Psychophysiol Biofeedback* 2010;35:207–17
36. Kent P, Laird R, Haines T: The effect of changing movement and posture using motion-sensor biofeedback, versus guidelines-based care, on the clinical outcomes of people with sub-acute or chronic low back pain-a multicentre, cluster-randomised, placebo-controlled, pilot trial. *BMC Musculoskelet Disord* 2015;16:131
37. Kim SS, Min WK, Kim JH, et al: The effects of VR-based Wii fit yoga on physical function in middle-aged female LBP patients. *J Phys Ther Sci* 2014;26:549–52
38. Krein SL, Kadri R, Hughes M, et al: Pedometer-based internet-mediated intervention for adults with chronic low back pain: randomized controlled trial. *J Med Internet Res* 2013;15:e181
39. Magnusson ML, Chow DH, Diamandopoulos Z, et al: Motor control learning in chronic low back pain. *Spine* 2008;33:E532–8
40. Massé-Alarie H, Flamand VH, Moffet H, et al: Peripheral neurostimulation and specific motor training of deep abdominal muscles improve posturomotor control in chronic low back pain. *Clin J Pain* 2013;29:814–23
41. Miller JS, Stanley I, Moore K: Videotaped exercise instruction: A randomized controlled trial in musculoskeletal physiotherapy. *Physiother Theory Pract* 2004;20:145–54
42. Newton-John TR, Spence SH, Schotte D: Cognitive-behavioural therapy versus EMG biofeedback in the treatment of chronic low back pain. *Behav Res Ther* 1995;33:691–7
43. Nouwen A: EMG biofeedback used to reduce standing levels of paraspinal muscle tension in chronic low back pain. *Pain* 1983;17:353–60
44. Park JH, Lee SH, Ko DS: The effects of the Nintendo Wii exercise program on chronic work-related low back pain in industrial workers. *J Phys Ther Sci* 2013;25:985–8
45. Rittweger J, Just K, Kautzsch K, et al: Treatment of chronic lower back pain with lumbar extension and whole-body vibration exercise: a randomized controlled trial. *Spine* 2002;27:1829–34
46. Stuckey SJ, Jacobs A, Goldfarb J: EMG biofeedback training, relaxation training, and placebo for the relief of chronic back pain. *Percept Mot Skills* 1986;63:1023–36
47. Unsgaard-Tøndel M, Fladmark AM, Salvesen Ø, et al: Motor control exercises, sling exercises, and general exercises for patients with chronic low back pain: a randomized controlled trial with 1-year follow-up. *Phys Ther* 2010;90:1426–40
48. Yang J, Seo D: The effects of whole body vibration on static balance, spinal curvature, pain, and disability of patients with low back pain. *J Phys Ther Sci* 2015;27:805–8
49. Hides JA, Richardson CA, Jull GA: Long-term effects of specific stabilizing exercises for first-episode low back pain. *Spine* 2001;26:E243–8
50. Geisser ME, Ranavaya MA, Haig AJ, et al: A meta-analytic review of surface electromyography among persons with low back pain and normal, healthy controls. *J Pain* 2005;6:711–26
51. Ferreira PH, Ferreira ML, Hodges PW: Changes in recruitment of the abdominal muscles in people with low back pain: ultrasound measurement of muscle activity. *Spine* 2004;29:2560–6
52. Hodges PW, Richardson CA: Altered trunk muscle recruitment in people with low back pain with upper limb movement at different speeds. *Arch Phys Med Rehabil* 1999;80:1005–12
53. Hodges PW, van Dillen L, McGill S, et al: Integrated clinical approach to motor control interventions in low back and pelvic pain, in Hodges P, Cholewicki J, van Dieën J (eds): *Spinal Control: The Rehabilitation of Back Pain*, London, United Kingdom, Churchill Livingstone, 2013, pp. 243–309
54. Dankaerts W, O'Sullivan PB, Straker LM, et al: The inter-examiner reliability of a classification method for non-specific chronic low back pain patients with motor control impairment. *Man Ther* 2006;11:28–39
55. Fersum KV, Dankaerts W, O'Sullivan PB, et al: Integration of subclassification strategies in randomised controlled clinical trials evaluating manual therapy treatment and exercise therapy for non-specific chronic low back pain: a systematic review. *Br J Sports Med* 2010;44:1054–62
56. O'Sullivan K, O'Sullivan L, O'Sullivan P, et al: Investigating the effect of real-time spinal postural biofeedback on seated discomfort in people with non-specific chronic low back pain. *Ergonomics* 2013;56:1315–25
57. Ribeiro DC, Sole G, Abbott JH, et al: The effectiveness of a lumbopelvic monitor and feedback device to change postural behavior: a feasibility randomized controlled trial. *J Orthop Sports Phys Ther* 2014;44:702–11
58. Kamper SJ, Apeldoorn AT, Chiarotto A, et al: Multidisciplinary biopsychosocial rehabilitation for chronic low back pain. *Cochrane Database Syst Rev* 2014;CD000963
59. Hicks GE, Fritz JM, Delitto A, et al: Preliminary development of a clinical prediction rule for determining which patients with low back pain will respond to a stabilization exercise program. *Arch Phys Med Rehabil* 2005;86:1753–62
60. O'Sullivan P: Diagnosis and classification of chronic low back pain disorders: maladaptive movement and motor control impairments as underlying mechanism. *Man Ther* 2005;10:242–55
61. Friedrich M, Gittler G, Halberstadt Y, et al: Combined exercise and motivation program: effect on the compliance and level of disability of patients with chronic low back pain: a randomized controlled trial. *Arch Phys Med Rehabil* 1998;79:475–87
62. Härkäpää K, Järvikoski A, Mellin G, et al: Health locus of control beliefs and psychological distress as predictors for treatment outcome in low-back pain patients: results of a 3-month follow-up of a controlled intervention study. *Pain* 1991;46:35–41
63. Cecchi F, Pasquini G, Paperini A, et al: Predictors of response to exercise therapy for chronic low back pain: result of a prospective study with one-year follow-up. *Eur J Phys Rehabil Med* 2014;50:143–51
64. Jordan JL, Holden MA, Mason EE, et al: Interventions to improve adherence to exercise for chronic musculoskeletal pain in adults. *Cochrane Database Syst Rev* 2010;CD005956
65. Laird RA, Gilbert J, Kent P, et al: Comparing lumbo-pelvic kinematics in people with and without back pain: a systematic review and meta-analysis. *BMC Musculoskelet Disord* 2014;15:229
66. Luomajoki H, Kool J, de Bruin ED, et al: Reliability of movement control tests in the lumbar spine. *BMC Musculoskelet Disord* 2007;8:90
67. Mieritz RM, Bronfort G, Jakobsen MD, et al: Reliability and measurement error of sagittal spinal motion parameters in 220 patients with chronic low back pain using a three-dimensional measurement device. *Spine J* 2014;14:1835–43
68. O'Sullivan K, Galeotti L, Dankaerts W, et al: The between-day and inter-rater reliability of a novel wireless system to analyse lumbar spine posture. *Ergonomics* 2011;54:82–90
69. Bauer CM, Rast FM, Ernst MJ, et al: Concurrent validity and reliability of a novel wireless inertial measurement system to assess trunk movement. *J Electromyogr Kinesiol* 2015;25:782–90

 © 2016 Wolters Kluwer Health, Inc. All rights reserved.

Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.