Practicability of segmental stabilizing exercises in the context of a group program for the secondary prevention of low back pain. An explorative pilot study

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Aim. **Segmental stabilizing exercises (SSE) for specific dysfunction of local muscles (*m. transversus abdominis*, *m. multifidus*, pelvic floor muscles and diaphragm pelvis) have been advocated in patients with low back pain (LBP). The specific aims of this study were to examine: 1) whether participants of a group program learn SSE; 2) whether they respond to SSE with a reduction in present LBP and 3) to what extent people report using SSE in daily living.**

Methods. **One-hundred nurses participated in this explorative pilot study. Data from a 12-week multimodal program including SSE as intervention for the prevention of LBP were analysed. The prone test was taken as an indicator for the participants' ability to perform SSE correctly. Present back pain was assessed on a numerical rating scale (0-10). A compliance questionnaire and a transfer questionnaire assessed compliance and transfer of SSE into daily living.**

Results. **After the intervention, 72% of participants were able to perform SSE correctly as measured by the prone test. Between 48% and 78% of the participants with present LBP experienced a minimal, clinically important change (minimal clinical changes, [MCC]) while performing SSE. No strong interrelations between the ability to correctly perform SSE and the MCC of LBP could be identified. Participants reported exercising SSE for 12 min on average 4-5 days a week. At 3 months after the intervention, 76% of participants reported using SSE "always" in their work with patients.**

Conclusion. **First findings are that SSE can be learned by the majority of the participants of a group program for the prevention of LBP. Additionally, SSE reduces present LBP and so can help people with LBP learn to help themselves. We are unable to explain how participants benefited from SSE even when they were unable to perform SSE correctly, as measured by the prone test.**

Key words: Low back pain, prevention and control - Exercises - Rehabilitation.

The stability of the spine is provided by: 1) the passive system (bone and joint structures and ligaments); 2) the active system (spinal muscles and the neural control unit). Under normal conditions these systems work together in harmony, providing the spine with the necessary mechanical stability.[1] The role of the active neuromuscular system in spinal stability should not be underestimated since the passive system is unstable when exposed to forces far less than that of body weight;[2] however, the muscles modulate spinal stiffness to match the demands of stability and movement.[3]

Based on anatomic characteristics, Bergmark identified muscles as either "global" or "local".[4] Global muscles are large superficial muscles crossing multiple segments that control spinal motion, orientation and balance. Local muscles cross one or more seg-

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ments and have a limited moment arm to move the joint, controlling intervertebral motion. The *m. transversus abdominis* and the deep fibres of the lumbar multifidus are local muscles of the lumbar spine and work in co activation with the diaphragm and the pelvic floor muscles.[5]

Clinical instability of the spine is a significant cause of low back pain (LBP).[1] And there is a considerable body of evidence showing dysfunction of local muscles in patients suffering from LBP. Patients with acute unilateral LBP had marked asymmetry of the *multifidus* cross sectional area, with the smaller muscle on the side of the symptoms.[6] Another study showed that *multifidus* muscle cross sectional area recovery was not spontaneous on remission of painful symptoms. The authors concluded that this may be the reason for the high recurrence of LBP following an initial episode.[7] As regards the *m. transversus abdominis*, researchers found a motor control deficit in patients with LBP in contrast to healthy controls.[8-10] A delay in the feed-forward contraction of the *m. transversus abdominis* was detected. It is hypothesized that this results in inefficient muscular stabilisation of the lumbar spine.[8, 10] Another study illustrated that participants with LBP had a significantly smaller increase in *m. transversus abdominis* thickness and less EMG activity during isometric low load tasks with their limbs suspended than subjects without LBP.[10] This reinforces the idea that automatic control of the *m. transversus abdominis* is altered in people with LBP. In brief, functioning of the local muscle system seems to play an important role in preventing LBP.

Based on findings of specific dysfunction of local muscles, segmental stabilizing exercises (SSE) have been advocated.[11] SSE focus on re-education of a precise co-contraction pattern of local muscles of the spine. The use of SSE in daily living and in stressful back activity has been recognized as essential to rehabilitation and the prevention of further episodes of LBP.[12]

The effectiveness of SSE was demonstrated in a systematic review of randomised controlled trials.[13] Pain and disability improved in participants with chronic LBP.[14] Patients with acute LBP suffered significantly fewer recurrences after specific treatment.[15]

However, there is a lack of knowledge about the altered ability to perform SSE correctly after an intervention. Furthermore, nothing is known about the influence of SSE on present LBP and whether participants follow recommendations to transfer SSE into daily living.

In an attempt to answer these questions, we analyzed the data of one arm of a randomized controlled trial on the secondary prevention of LBP in nurses. For economic reasons, we chose a group setting for this study. Additionally, there is a lack of knowledge about SSE in a group setting.

The objective of this study was to examine the practicability and effects of, and the compliance with, SSE in a multidisciplinary group setting to prevent LBP. Our specific aims were to examine: 1) whether group program participants a learn to perform SSE correctly; 2) whether participants respond to SSE with a reduction in present LBP; and 3) to what extent participants report using SSE in daily living.

Materials and methods

Design and participants

This pilot study was part of a randomised controlled trial comparing a multimodal with an exercise prevention program. The inclusion criteria were: 1) employment as nurses; 2) age 18 to 3 years before retirement; 3) at least one LBP episode in the last 2 years; 4) signed informed consent. An exclusion criterion was LBP leading to a sick certificate. Of the 212 nurses enrolled into the study, 202 were included. The study is described in detail elsewhere (Limm H, Ewert T, von Garnier K, Freumuth R, John J, Rackwitz B *et al.* Effectiveness of a multidisciplinary prevention program against low back pain: a randomized controlled trial in a nursing population. Submitted to Eur J Pain).

The following report refers only to the multimodal program; 100 participants were randomly assigned to this group.

Interventions

The multimodal prevention program consisted of 18 units of 90-min sessions conducted over a period of 13 weeks. The program syllabus comprised general exercise, educational and workplace-specific back school classes, increase of workload tolerance, psychological interventions and SSE. Each group consisted of up to 12 participants. The SSE comprised 7 sessions (1 single and 6 group interventions) over 8 weeks. The duration of each session was 45 min. SSE were taught as described by Richardson *et al.* [11] The challenge was to develop a concept for teaching SSE in a group setting as SSE have so far only been recorded for single interventions. It is known that individual feedback is crucial for these exercises (*e.g.* through the therapist, the pressure biofeedback unit, the ultrasound imaging). To compensate for reduced individual feedback by the therapist in a group situation, specially designed partner exercises were conducted to provide observational learning in addition to the usual feedback elements. Structured and easy to follow pictorial handouts were designed to facilitate successful participation during the courses and at home. The participants were encouraged to practice SSE about 5-10 min twice a day and to integrate them into their daily living. SSE were gradually introduced into the general exercise program, workplace-specific back school classes and work hardening interventions.

Measurements

Baseline characteristics

Sociodemographic and comorbidity [16] data were collected before baseline at the screening procedure. At baseline, the Korff index was calculated to describe the severity and type of pain.[17] The study participants were asked to document the number of days in pain in the previous 12 months. An unpublished questionnaire, developed according to the "Methods in Health Economic Evaluation" working group standards to measure resource use and costs, was additionally deployed to describe the use of health care services during the last 12 months.[18]

Questionnaires on SSE

At the beginning of each new SSE intervention, participants completed a self-developed questionnaire to assess their compliance with performing home exercises. They were asked about how many days and for how long (minutes) they practiced SSE over the last week. An additional questionnaire given at the 3-month follow-up assessment investigated transfer of SSE to daily living. A questionnaire item that assessed for transfer of SSE into back stressing activity asked participants whether they had performed SSE during the Biering-SØrensen and the progressive isoinertial lifting evaluation (PILE) tests. The Biering-SØrensen test measures trunk extensor endurance by assessing holding time.[19] The PILE test assesses lumbar lifting capacity.[20]

Functional assessment of SSE

All tests described below were measured pre- and post-intervention. The assessor was blinded at post-assessment to baseline data. A modified version of the "prone test" described by Richardson *et al.* in 2004 was used to assess the participants' ability to perform SSE correctly.[21] Part one, which is described in detail below, was filled out by the assessor, grades the participant's ability according to the prone test results. Part two consisted of items enquiring into how participants rated on a numerical rating scale (NRS) (0-10) their ability to perform the prone test and about back pain before and during the test. The assessor scored the participants' prone test results using the same scale.

Prone test procedure

A modified version of the prone test, described by Richardson *et al.*, was performed to assess the independent action of the *m. transversus abdominis* – so-called "abdominal hollowing" – by the global abdominal muscles.

At baseline, prior to the test, each participant received an individual, standardized introduction lasting 20 min. It included information on the anatomy and function of global and local muscles, the importance of activating local spinal muscles independently of global muscles, and on how to relax the abdomen and to perform selective "abdominal hollowing". The action was demonstrated in four-point kneeling and the participant was instructed 3 times in prone position. The participant was instructed to perform the exercise without spinal or pelvic movement and with relaxed breathing.

Before the test, a pressure biofeedback unit (PBU) was placed on the abdomen centrally, below the navel, with the distal edge of the pad in line with the right and left anterior superior iliac spines. The PBU was inflated to 70 mmHg. The test procedure was conducted according to a fixed routine of instructions: fully relax the abdomen and breathe normally; draw in the lower abdominal wall without moving the spine or pelvis; maintain relaxed breathing while holding the contraction for 10 s, fully relax the abdomen. The test was repeated 3 times. A 20-s break was given between the tests. The assessor performed four observation tasks during the test: of the PBU dial, of the trunk for spinal or pelvic movement, of the breathing pattern and palpation of both sides of the abdominal wall.

The test results were categorized into two parts:

1. The participant achieved a positive prone test result (Yes/No). The prerequisites for "yes" were: pressure fall on the PBU of at least 2 mm Hg, absence of spinal and pelvic movement, relaxed breathing pattern and absence of bulging of the abdominal wall;

2. If 1. =Yes: The scores of the ability to achieve a positive prone test result were collected and recorded on a scale (1-4) as described below. The participant was able to perform selective "abdominal hollowing":

1) less than 10 s;
2) once for 10 s;
3) twice for 10 s or
4) three times for 10 s.

Statistical analysis

The analysis was based on an available-case-analysis of the intention-to-treat approach.[22] A withdrawal analysis (Mann-Whitney U test, χ^2-test) was applied to all subject characteristics to determine whether those who failed to return for the post-assessment differed from those remaining. Since all data were analyzed exploratively, no α-adjustment was conducted.

All continuous variables were examined for normal distribution using the Kolmogorov-Smirnow Test. Variables for baseline characteristics (Table I) were normally distributed. Since most remaining variables had either a skewed distribution or were on an ordinal scale, nonparametric tests were used for the analysis. The following tests were conducted: the Spearman-roh for correlations between variables; the Wilcoxon to examine pre-post differences for continuous data; the χ^2-test for binary data, the interrater correlation coefficient (ICC) for correlations between two raters (participant and assessor). To examine the clinical meaningfulness of changes in present low back pain (NRS) during SSE (prone test), minimal clinical changes (MCC) were predefined according to the literature: reduction of 2 points[23] or alternatively 30% [24] on the pain rating scale. Both alternatives were calculated with the χ^2-test to look for interrelations with the prone test results. The hypothesis was that those participants with a positive prone test result would respond more often with an MCC in present back pain than those with a negative prone test result.

TABLE I.—*Baseline characteristics.*

Characteristics	n = 92
Age (years)	37.9±11.6
Gender (female)	84 (91.3%)
Partnership (yes)	53 (57.6%)
High school diploma	18 (19.6%)
Working fulltime	74 (80.4%)
Body Mass Index (kg/m^2)	25.6±5.6
Weekly sports activities	2.0±2.0
Comorbidity score	1.3±1.5
Pain types:**	
No pain	1 (1.1%)
Pain type I	58 (63.7%)
Pain type II	21 (23.1%)
Pain type III	9 (9.9%)
Pain type IV	2 (2.2%)
Days in pain (LBP) in the last 12 months	77.9±99.6
Participants with sick leave in the last 12 months	12 (13%)
Use of health care services in the last 12 months	
Participants reporting physical visits	38 (41.3%)
Participants reporting non-physician service visits***	28 (30.8%)
Participants using analgesic medication	45 (48.9%)

Plus minus values are the means±SD.
** Type I: low disability, low pain intensity; type II: low disability, high pain intensity; type III: high disability, moderately limiting; type IV: high disability, severely limiting [17] (pain in the last 12 months).
*** Including physiotherapist, occupational therapist, psychological therapist and alternative practitioner visits.
LBP denotes low back pain.

Results

Participants

Of the 100 study subjects, 8 (8%) dropped out before baseline assessment. The characteristics of the remaining 92 subjects are shown in Table I. Twelve (12%) did not show up for the post-assessment and 7 (7%) failed to return the transfer questionnaire at the 3-month follow-up assessment. Accordingly, 80 (80%) could be included into the data analysis for baseline and post-measurement and 76 (76%) at the 3-month follow-up. Missing data varied between 0 and 2 per instrument. Exceptions were the questions accompanying the Biering-SØrensen and the PILE test, with a maximum of 9 and 13 omissions, respectively.

The withdrawal analysis compared the 12 participants who failed to return for post-assessment with the remaining 80. The results showed no differences (P>0.05) in baseline characteristics, except for the variable "Participants reporting nonphysician service visits" (the withdrawals reported more visits; P=0.024).

The mean attendance in the program was 12.4±2.9

(range 6-18); the mean attendance in the SSE sessions was 5.8±1.0 (range 3-7).

Outcome analysis

Learning SSE

Prone test results.—Thirty-nine (50%) participants had positive prone test results at baseline and 57 (72%) at post-assessment (P<0.001). Those who had a positive prone test result at baseline also improved their ability from a median score (percentiles: 25;75) of 2 (1;3) to 3 (2;4) (P=0.001) (Figure 1).

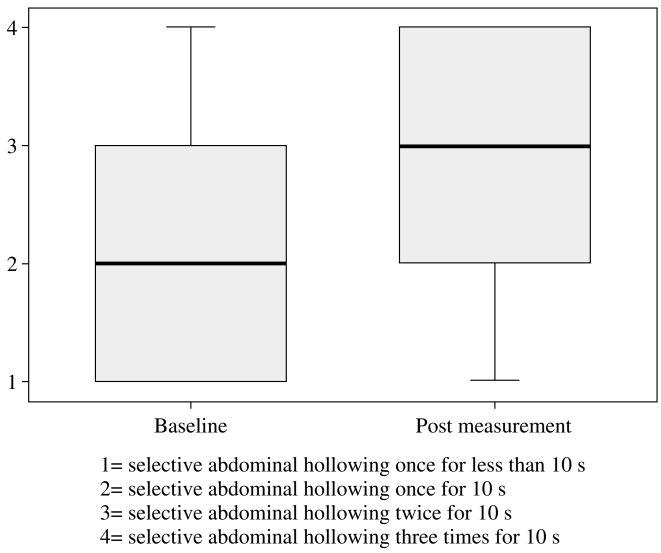

Figure 1.—Improvement in the ability to perform the prone test.

Ability to judge prone test results.—The correlation between the judgment of the assessor and the participant was r=0.427 (P=0.001) at baseline and r=0.436 (P<0.001) at post-measurement. When the participants were split into 2 groups according to positive or negative prone test result (1=positive and 2=negative), the correlation at baseline was r=0.411 (P=0.003) for group 1 and r=0.186 (P=0.717) for group 2.; at post-measurement the correlation was r=0.454 (P<0.001) for group 1 and r=0.034 (P=0.702) for group 2. This showed that there was a better correlation between those participants with a positive prone test result to estimate their ability and the assessor's judgment than those who were unable to successfully accomplish the prone test.

Changes in present low back pain while performing SSE

LBP before and after the prone test.—At baseline, participants reported only mild LBP (NRS 0-10) before 0(0;1)* and even less after 0(0;0)* the prone test (P=0.001)*. Similarly, at post-assessment participants reported 0(0;1)* before and 0(0;0)* after the test (P<0.001).

When the study sample was split into 2 groups (those who had LBP before the prone test [group A]) and those who did not (group B]) and the baseline characteristics compared, group A (27 participants) had a mean LBP score of 2.4±1.5 before the prone test

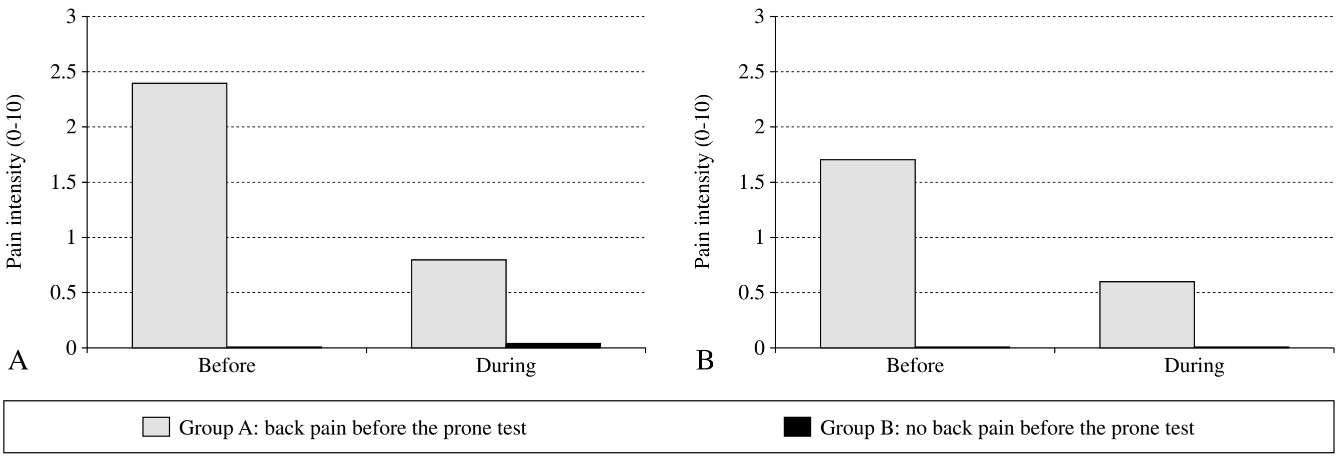

Figure 2.—A) Back pain before and during the prone test at baseline. B) Back pain before and during the prone test at post-measurement.

TABLE II.—*Cross-table for interrelation between back pain reduction and prone test results.*

Baseline (numbers represent participants)	Responder:* 2 points/30%	Non-responder:* 2 points NRS/30%	Total
Positive prone test result	5/5	9/9	14
Negative prone test result	3/1	10/12	13
Total	8/6	19/21	27

*Responder: participants who experienced a reduction in low back pain from before to after the prone test on a NRS (0-10) of 2 points [23] respectively 30%.[24] Nonresponder: participants who do not fulfil these requirements.

TABLE III.—*Cross-table for interrelation between back pain reduction and prone test results.*

Post-measurement (numbers represent participants)	Responder:* 2 points NRS/30%	Non-responder:* 2 points NRS/30%	Total
Positive prone test result	4/1	1/4	5
Negative prone test result	8/6	10/12	18
Total	12/7	11/16	23

*Responders: participants who experienced a reduction in low back pain from before to after the prone test on a NRS (0-10) of 2 points [23] respectively 30%.[24] Nonresponders: participants who do not fulfil these requirements.

which decreased to 0.8±1.4 (P<0.001). Of these 27, LBP scores improved in 21, remained unchanged in 5, and increased in one; in group B (51 participants) only one participant experienced LBP during the prone test (2 points on the NRS) which indicated an increase in the mean LBP score of 0.04±0.3 (P=0.317) (Figure 2A).

At post-assessment before the prone test, 23 participants in group A had a mean LBP score of 1.7±0.9 which dropped to 0.6±0.7 (P<0.001); 16 had lower LBP scores and the present LBP remained unchanged in 7; in group B (56 participants) no one experienced LBP during the prone test (Figure 2B).

Interrelation between SSE (prone test) and responders/nonresponders with LBP.—Responders were defined as those subjects who achieved a predefined MCC of LBP on the NRS (0-10). Calculations for the MCC of 2 points[23] / 30% [24] reduction in LBP, respectively, showed that at baseline of the 27 subjects with LBP 19 (70%) / 21 (78%) responded to SSE (prone test) with an MCC in LBP. Interrelations between responders and prone test results were P=0.472 / P=0.080. At post-assessment, of the 23 with LBP 11 (48%) / 16 (70%) responded to SSE (prone test) with an MCC in LBP. Interrelations between responders and prone test results were P=0.159 / P=0.567 (Tables II, III).

USING SSE IN DAILY LIVING.

SSE at home and at work.—Participants practiced SSE for a mean of 52± 5.3 min at home each week on an average of 4.4±1.4 days per week during the intervention period. At post-measurement, correlations between exercising SSE and prone test results were r=-0.017 (P=0.884). At the 3-month follow-up, 62% of subjects reported exercising SSE at least once a week. Correlations between exercising SSE at the 3-month follow-up and prone test results were r=-0.186 (P=0.116).

Using SSE in back stressing activity.—At post-measurement, 76% of subjects reported using SSE during the PILE test (lifting capacity) and 63% during the Biering-SØrenson test (endurance of back-extending muscles). At 3-month follow-up, 76% of subjects referred using SSE while maneuvering patients "always" or "often", 20% "sometimes" and 4% "never".

Discussion

Baseline characteristics show an active, working, middle-aged mostly female population and, despite many days in pain, with mild disability.

Our first objective was to examine whether participants in a group program can learn SSE. In brief, our results show that after the intervention period 72% of subjects had a positive prone test result. Although numerous studies use SSE as an intervention,[7, 14, 15, 25-28] they do not report on how many participants achieve positive prone test results, making comparison with our data impossible. Interestingly, 50% of subjects had a positive test result at baseline after a 20-min introduction. This is in line with nonintervention studies using the prone test with healthy subjects.[29, 30] Although these studies used different premises to determine a positive prone test result, positive prone test results were reported in 43% and 47% of subjects, respectively.

Notably, all our participants had a history of LBP (as defined in the inclusion criteria), but 50% nevertheless achieved a positive prone test result. This adds to the growing body of evidence for a weak interrelationship between LBP symptoms and prone test results. Although researchers have tried to establish rules to correctly classify LBP patients, findings are highly contradictory.[29-32]

Besides the ability to perform an exercise technique correctly, patients need to be able to judge their capability properly, ensuring that they practice according to the recommendations. Our findings show that the correlation between the assessor's and the participant's judgment of the prone test results did not differ substantially between baseline and post-measurement. The correlations of participants with a positive prone test result had a middle value and those with negative result had a low value, according to Sedlmeier's grading of correlation coefficient.[33] But this might be an indication that participants with poor body awareness have more trouble learning SSE.

Our second objective was to examine whether present LBP improves whilst performing SSE. Our results show that those participants with LBP before the prone test experienced significant pain reduction during the test, with chronic LBP patients scoring a reduction of 2 points on the pain rating scale, or a reduction of about 30%, which represents a minimal clinically important change (MCC).[23, 24] We can, therefore, be rather confident that a pain reduction of 1.6 (66.7%) at baseline and 1.1 (64.7%) at post-measurement, as experienced by our study sample during the prone test, can be considered as a clinically important difference. This leads to the conclusion that for participants with present LBP, SSE conducted in prone position was a successful self help method. Some questions arise, however, about the interrelation between prone test results and the participants who responded with an MCC in LBP. The data in Table II and Table III show that our hypothesis for a strong interrelation could not be confirmed. Why participants experienced an MCC in LBP even though they were unable to correctly perform SSE as measured with the prone test remains unclear.

The third objective of this study was to examine to what extent people report using SSE in daily living. SSE therapists recommend 10-15 min practice daily.[14, 27] Our results show that during the intervention period the participants performed SSE for an average of 12 min 4-5 days a week. We are unable to compare our findings as there is a lack of data about compliance rates in other SSE-studies. Nevertheless, taking practical experience into account, this seems to be satisfactory. Astonishingly, 62% of subjects still reported exercising SSE at least once a week 3 months after the end of intervention. This might be due to the good feasibility of SSE, which can be undertaken in practically any position, setting and time of day. On the other hand, there might have been a bias due to desirable response.

Correlations between exercising SSE at home during the time of intervention and positive prone test results at post-measurement were weak; therefore, the frequency of practicing SSE did not seem to improve prone test results.

Correlations between SSE at 3-month follow-up and positive prone test results at post-measurement were also low. This tells us that participants kept practicing SSE independently of their ability. The fact that SSE does not help those who are unable to perform them correctly could be problematic, as these participants did not try other forms of intervention to prevent and/or reduce their LBP. On the other hand, the prone position is just one of many in which SSE can be performed. Participants could have chosen other positions, exercised correctly and so benefited from SSE.

The majority of participants reported using SSE in back stressing activity. Unfortunately, we have no data from other studies to compare our results. Experience of physiotherapists nevertheless tells us that these results are above average. Transferring any kind of exercise into daily living is difficult. Integrating SSE into the other modules of the multimodal program might have enhanced the take over. SSE also seems to be a technique that is easy to apply, but here, again, we have to consider a possible bias due to desirable response.

Limitations of the study

This study is considered an explorative pilot study. In light of the many methodological limitations described below, the results can only be interpreted as first indicators.

First, this article analyses only a part of a two-arm randomized study and, therefore, does not have a control group. This is problematic as the results cannot be attributed to the intervention alone. Second, participation in the study was voluntary, so a selection bias of especially motivated nurses was very likely. Third, there are limitations regarding the data analysis. Most questionnaires were of our own design and not validated. Fourth, some shortcomings concern the prone test. The prone test assessor was only blinded for the baseline results at post-measurement; as she was the same person who conducted the intervention, she might have been influenced by her own expectations and by her contact with the participants. Another concern is that the validity and reliability of the prone test is not resolved, [34] even though it is widely used in practice and reflects the everyday reality of physiotherapy. Another limitation is that the corset action of the SSE relies on 4 different synergists: the *m. transversus abdominis*, the deep layers of the *mm. multifidii*, the diaphragm pelvis and the pelvic floor. So conclusions about the correct performance of SSE cannot be derived from the activation of the *m. transversus abdominis* alone, as assessed with the prone test.[12] Unfortunately, no feasible and reliable measurements for the other muscles exist at present.

Conclusions

Given the limitations of this explorative pilot study, the first indications are that SSE can be learned by the majority of participants of a group program for the prevention of LBP. SSE reduces present LBP during exercise and so can help LBP sufferers to help themselves. Participants in a multimodal program perform SSE at home and transfer them to their daily life. These findings need to be confirmed in randomized controlled trials. There is also a need for validated and reliable measurement instruments to assess the performance of SSE more credibly.

References

1. Panjabi M. Clinical spinal instability and low back pain. J Electromyogr Kinesiol 2003;13:371-9.
2. Nachemson A. The load on lumbar discs in different positions of the body. Clin Orthop 1966;45:107-22.
3. Hodges P. Lumbopelvic stability: a functional model of the biomechanics and motor control. In: Richardson C, Hodges P, Hides J editors. Therapeutic exercise for lumbopelvic stabilisation. London: Churchill Livingstone; 2004. p. 13-28.
4. Bergmark A. Stability of the lumbar spine. Acta Orthop Scand 1989;60 Suppl 230:1-54.
5. Hodges P. Abdominal mechanism and support of the lumbar spine and pelvis. In: Richardson C, Hodges P, Hides J editors. Therapeutic exercise for lumbopelvic stabilisation. London: Churchill Livingstone; 2004. p. 31-57.
6. Hides JA, Stokes MJ, Saide M, Jull GA Cooper DH. Evidence of lumbar multifidus muscle wasting ipsilateral to symptoms in patients with acute/subacute low back pain. Spine 1994;19:165-72.
7. Hides J, Richardson C, Jull G. Multifidus muscle recovery is not automatic after resolution of acute first-episode low back pain. Spine 1996;23:2763-9.
8. Hodges P, Richardson C. Inefficient muscular stabilization of the lumbar spine associated with low back pain: a motor control evaluation of trans*versus* abdominis. Spine 1996;22:2640-50.
9. Hodges P, Richardson C. Delayed postural contraction of trans*versus* abdominis in low back pain associated with movement of the lower limb. J Spinal Disord 1998;1:46-56.
10. Ferreira PH, Ferreira ML, Hodges PW. Changes in recruitment of the abdominal muscles in people with low back pain. Spine 2004; 22:2560-6.
11. Richardson CA, Jull GA. Muscle control - pain control. What exercises would you prescribe? Man Ther 1995;1:2-10.
12. Richardson C, Hodges P, Hides J. Therapeutic exercise for lumbopelvic stabilisation. A motor control approach for the treatment and prevention of low back pain. London: Churchill Livingstone; 2004.
13. Rackwitz B, de Bie R, Limm H, von Garnier K, Ewert T, Stucki G. Segmental stabilizing exercises and low back pain. What is the evidence? A systematic review of randomized controlled trials. J Clin Rehabil 2006;20:553-67.
14. O'Sullivan P, Twomey L, Allison G. Evaluation of specific stabilizing exercises in the treatment of chronic low back pain with radiologic diagnosis of spondylolysis or spondylolisthesis. Spine 1997;24:2959-67.
15. Hides JA, Jull GA, Richardson CA. Long-term effects of specific stabilizing exercises for first-episode low back pain. Spine 2001;26:243-8.
16. Sangha O, Stucki G, Liang M, Fossel A, Kath J. The self-administered comorbidity questionnaire: a new method to assess comorbidity for clinical and health services research. Arth Rheum 2003;49:156-63.
17. Korff von M, Ormel J, Keefe F, Dworkin S. Grading the severity of chronic pain. Pain 1992;50:133-49.
18. Krauth C, Hessel F, Hansmeier T, Wasem J, Seitz R, Schweikert B. Empirische Bewertungssätze in der gesundheitsökonomischen Evaluation - ein Vorschlag der AG Methoden der gesundheitsökonomischen Evaluation (AG MEG). Gesundheitswesen 2005;67:736-46.
19. Biering-Sørensen F. Physical measurements as risk indicators for low back trouble over a one-year period. Spine 1984;9:106-19.
20. Mayer T, Barnes D, Kishino N, Nichols G, Gatchel R, Mayer H *et al.* Progressive Isoinertial lifting evaluation. A standardized protocol and normative database. Spine 1988;13:993-7.
21. Hides J, Richardson C, Hodges P. Local segmental control. In: Richardson C, Hodges P, Hides J editors. Therapeutic exercise for lumbopelvic stabilisation. London: Churchill Livingstone; 2004. p.185-219.
22. The Cochrane Collaboration. Cochrane Handbook for Systematic Reviews of Intervention 4.2.5. http://www.cochrane.org/resources/handbook/index.htm.
23. Hägg O, Fritzell P, Nordwall A. The clinical importance of changes in outcome scores after treatment for chronic low back pain. Eur Spine J 2003;12:12-20.
24. Farrar JT, Young JP, LaMoreaux L, Werth JL, Poole RM. Clinical importance of changes in chronic pain intensity measured on a 11-point numerical pain rating scale. Pain 2001;94:149-58.
25. Niemistö L, Lahtinen-Suopanki T, Rissanen P, Lindgren KA, Sarna S, Hurri H. A randomized trial of combined manipulation, stabilizing exercises, and physician consultation compared to physician consultation alone for chronic low back pain. Spine 2003;28:2185-91.
26. Moseley L. Combined physiotherapy and education is efficacious for chronic low back pain. Aust J Physiother 2002;48:297-302.
27. Rasmussen-Barr E, Nilsson-Wikmar L, Arvidsson I. Stabilizing train-

ing compared with manual treatment in sub-acute and chronic low back pain. Man Ther 2003;8:223-41.
28. Kladny B, Fischer FC, Haase I. Evaluation of specific stabilitzing exercise in the treatment of low back pain and lumbar disk disease in outpatient rehabilitation. Z Orthop 2003;141:401-5.
29. Richardson C, Snijders C, Hides J, Damen L, Pas MS, Storm J. The relationship between the trans*versus* abdominis muscles, sacroiliac joint mechanics and low back pain. Spine 2002;27:399-405.
30. Herrington L, Davies R. The influence of Pilates training on the ability to contract the trans*versus* abdominis muscle in asymptomatic individuals. J Bodywork Movement Ther 2005;9:52-7.
31. Richardson CA, Jull GA, Richardson BA. A dysfunction of the deep abdominal muscles exists in low back pain patients. In: Richardson C, Hodges P, Hides J editors. Therapeutic exercise for lumbopelvic stabilization. London: Churchill Livingstone; 2004 .p. 191.
32. Cairns M, Harrison K, Wright C. Pressure biofeedback: a useful tool in the quantification of abdominal muscular dysfunction? Physiotherapy 2000;86:127-38.
33. Sedlmeier P. [Beyond the ritual of significance testing: alternative and supplementary methods]. Methods of Psychological Research-online, 1996. http://www.mpr-online.de.
34. Storheim K, BØ K, Pederstad O, Jahnsen R. Intra-tester reproducibility of pressure biofeedback in measurement of trans*versus* abdominis function. Physiother Res Int 2002;7:239-49.