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Measuring lumbar reposition accuracy in patients with unspecific low back pain – Systematic Review and Meta-analysis

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Abstract:

Study Design. Systematic review and meta-analysis.

Objective. To evaluate if patients with nonspecific chronic low back pain (NSCLBP) show a greater lumbar reposition error (RE) than healthy controls.

Summary of Background Data. Studies on lumbar RE in patients with NSCLBP present conflicting results.

Methods. A systematic review and meta-analysis of the available literature were performed to evaluate differences in RE between NSCLBP patients and healthy controls. Data on absolute (AE), constant (CE) and variable error (VE) were extracted and effect sizes (ES) were calculated. For the CE flexion pattern and active extension pattern, subgroups of patients with NSCLBP were analyzed. Results of homogeneous studies were pooled. Measurement protocols and study outcomes were compared. The quality of reporting and the authors´ appraisal of risk of bias were investigated.

Results. The original search revealed 178 records of which 13 fulfilled the inclusion criteria. The majority of studies showed that patients with NSCLBP produced a significantly larger AE (ES 0.81 [CI .13-1.49]) and VE (ES 0.57 [CI 0.05-1.09]) compared to controls. CE is direction- specific in flexion and active extension pattern subgroups of patients with NSCLBP (ES 0.39 [CI -1.09-0.3] and ES 0.18 [CI -.3-0.65], respectively). The quality of reporting and the authors' appraisal of risk of bias varied considerably. The applied test procedures and instrumentation varied between the studies, which hampered the comparability of studies.

Conclusions. Whilst patients appeared to produce a larger lumbar RE compared to healthy controls, study limitations render firm conclusions unsafe. Future studies should pay closer attention to power, precision and reliability of the measurement approach, definition of outcome measures and patient selection. We recommend a large, well powered, prospective randomised control study which uses a standardized measurement approach and definitions for AE, CE, and VE to address the hypothesis that proprioception may be impaired with CLBP.

Keywords: Low back pain, proprioception, spine, posture, review, meta-analysis, lumbar reposition error, lumbosacral region, lumbar spine, motor control, movement control

Key Points:

- Patients with NSCLBP tend to produce a larger lumbar RE compared to healthy controls.
- The applied test procedures and instrumentation varied between studies.
- We recommend a standardized measurement approach and the use of standardized and accurate definitions for lumbar reposition error to be used in future studies.

Mini Abstract:

A systematic review and meta-analysis were performed to investigate differences in lumbar reposition error (RE) between patients with non-specific chronic low back pain (NSCLBP) and controls. Patients with NSCLBP produce greater RE compared to controls. We recommend standardized measurement approaches and definitions for RE to be used in future studies.

Low back pain (LBP) affects up to 84% of people in industrialized countries[1]. In 2005, the total direct costs of LBP in Switzerland amounted to €2.6 billion[2]. Evidence recommends the use of a prognostic sub-classification including cognitive, physical and lifestyle factors for all chronic LBP (CLBP) patients who do not display underlying red flag disorders; specific pathoanatomical disorders or pain disorders driven from the forebrain with a dominance of non-organic factors [3,4,5,6,7]. The physical factor of this classification system includes a large subgroup of patients with mal-adaptive movement or control disorders[3,4,5,6]. Movement and control disorders are interpreted as mal-adaptive primary physical compensations, after an initial painful episode, which drive the CLBP state[3]. They presumably lead to a proprioceptive deficit, due to stress on local muscle spindles and joint receptors in the painful area resulting from stress to a joint caused by an individual's maladaptive movement[3]. Proprioceptive deficits may lead to altered central sensory-motorcontrol mechanisms and disrupted body schema. Subsequently abnormal joint and tissue loading during daily activities and postures may affect local proprioceptors and maintain this vicious circle[7,8,9,10,11,12,13]. Reposition error (RE) is regarded as a measure reflecting proprioception deficits in the lower spine and typically involves participants trying to reproduce a specific target body position[14,15,16].

RE can be expressed as absolute error (AE), constant error (CE), or variable error (VE). AE represents the error magnitude and is defined as the absolute difference between the target lumbar angle and actual lumbar angle. CE represents the error magnitude direction such that CE indicates bias towards a particular direction where negative CE typically represents a bias in the undershooting direction. VE describes the variability of the subjects' performance equivalent to the standard deviation of RE. High VE values reflect high variability in repositioning[17].

Using lumbar RE as an outcome measure several studies have investigated deficits in proprioception in patients with LBP[11,12,14,15,16,17,18,19,20,21,22,23,24,25]. In these tests, patients are asked to reproduce a specific (e.g., neutral) lumbar position after performing an active or passive movement. Some studies reported an increased lumbar RE of patients with LBP compared to a healthy population[12,14,15,16,18,21,22,23]. Classifying patients with nonspecific CLBP (NSCLBP) based on movement and control impairments[3] revealed direction-specific differences in lumbar RE between flexion pattern (FP) and active extension pattern (AEP) subgroups of NSCLBP patients[14,16]. A recent RCT showed that these lumbar spine position sense deficits were treatable with a classification guided postural intervention[26]. However, other studies have shown no differences between patients with LBP and healthy controls when testing for lumbar position sense[17,19,21], even after they were sub-grouped according to a McKenzie classification system or ICD-10 codes[17].

As it is discussed controversial if proprioception is altered in patients with NSCLBP that display physical factors a meta-analysis of the earlier results is advisable and a systematic review may contribute to a better understanding of this issue.

Measurement procedures for assessing RE and findings vary among studies in patients with LBP and healthy controls. Therefore, the aim of this systematic review and meta-analysis was to evaluate if patients with NSCLBP produce a greater lumbar RE. Thus, a statistical pooling of homogeneous study results was performed. Furthermore, design and measurement methods of RE studies were compared to state recommendations for further research.

MATERIALS AND METHODS

Data Sources and Searches

Study identification commenced by electronic searching, using the MEDLINE (through Pubmed), CINAHL, and Cochrane Library, on articles published between January 1, 1990 and September 30, 2013. Search terms used were low back pain, proprioception, position sense, kinesthesis, reposition, and repositioning. Both Medical Subject Headings terms and free text words were entered. A combination of these terms was used to extract a comprehensive list of articles, from which the titles and abstracts were screened for eligibility. An additional search for grey literature on issue-specific databases[27,28,29], citation tracking, and key author searches was conducted.

Eligibility Criteria

The following criteria were applied to determine the eligibility of each study for inclusion in the meta-analysis:

- patients with NSCLBP and healthy controls,
- at least one measure reflecting RE (AE, CE, VE),
- published in English or German

Two reviewers independently evaluated records for eligibility. Disagreement was resolved by discussion and consensus. To avoid duplication in pooling, data were included only once if they were reported in previously published work.

Quality Assessment

Two reviewers independently analysed the quality of the included studies as recommended by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration[30,31]. Accordingly, the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement was used to analyze both the quality of reporting and the author's 'appraisal of risk of bias'[32,33]. Discrepancies were solved by consensus. Results were summarized in tabular form to enable a sensitivity analysis based on quality criteria.

Data Analysis

Two reviewers independently extracted information of each study including the setting of the study, characteristics of patients, inclusion and exclusion criteria, instrumentation, test protocol, and outcomes (tasks and variables). Those data were presented narratively in tabular form. Data on reliability and measurement error of the test protocols were extracted and presented in tabular form.

Descriptive data for continuous variables were expressed as mean and standard deviation (SD). The Cochrane collaboration's Revman 5.2.7 software was used for a pooled data analysis. Data were reported as AE, CE, or VE. Effect sizes of single studies were expressed as Hedges g or Cohens r, if the original data was non-normally distributed, with 95% confidence intervals. Those studies describing results reflecting AE, CE, and VE evaluated with neutral-slumped-neutral sitting were used for meta-analysis using a random effects model, subgrouped for adults and adolescents. Neutral-slumped-neutral was chosen as pooling criteria because six studies used this setup. All other setups were used once. Additionally, CE was analyzed independently for FP and AEP subgroups of NSCLBP, as CE is direction specific in these subgroups[14,15,16]. As the definition of undershooting into a flexed position and overshooting into an extended position varied between the studies, we applied a common definition and changed the sign of study results in one study[16] according to this definition. Undershooting into a flexed position was given a negative sign while overshooting into an extended position was given a positive sign. To assess heterogeneity, the Q-statistic and its *p* value were calculated. I^2 was calculated as a mass of between-study heterogeneity (for each set of effect sizes) according to Borenstein[34]. The meta-analyses were first performed including all studies fulfilling the above criteria. As a sensitivity analysis, the meta-analysis were then repeated by excluding studies with poor quality of reporting and studies appearing as outliers to assess their influence on the meta-analysis.

RESULTS

The search revealed 178 records; 31 of them were screened in full-text (Figure 1). Eighteen studies were excluded due to study design (e.g., interventional studies, no healthy control group), outcome variables (no AE, CE, VE), or the character of included subjects (no NSCLBP). A total of 13 studies[11,12,14,15,16,17,18,19,20,21,22,23,24,25] fulfilled the inclusion criteria (Table 1). Four out of thirteen of the included studies did not provide sufficient data on reposition error (mean, SD)[17,20,21,22]. Upon contacting the corresponding authors, we did not receive this information from them. The overall loss of subjects was 148 patients with NSCLBP and 86 controls.

Table 2 summarizes the applied test procedures and instrumentation, which varied largely between the studies. Table 3 shows the reported variables and calculated effect sizes. The majority of the studies showed that NSCLBP patients produced a significantly larger AE and VE compared to controls. The quality of reporting and the authors' appraisal of risk of bias (STROBE) varied considerably. Some studies do not present information on risk of bias and attempts to reduce bias (Table 4). Reporting on reliability and measurement error was inconsistent with studies not reporting either or referring to measurement error and reliability of the measurement device (Table 5) (12, 15, 18, 19).

Six studies were included in the meta-analysis as they shared the same measurement protocol (neutral-slumped-neutral in sitting) (Figure 2). The studies were subgrouped, according to the age of the participants, into adults(12,15,16,24,25) and adolescents(14).

The overall effect size of 0.81 [CI 0.13-1.49] illustrates that patients with LBP produce a larger AE than healthy controls. The overall heterogeneity of study effects was considerable (I^2=83%, p<.05); it was no longer restricted to studies with poor quality of reporting but to all studies included in the meta-analysis. Heterogeneity did not change when single studies were excluded from the meta-analysis.

Two studies were included in a meta-analysis on VE (Figure 3). The overall effect size for VE of 0.68 [CI 0.01-1.36] illustrates that patients with NSCLBP have a higher deviation of the reposition error than healthy controls. The heterogeneity of study effects was substantial and significant (I^2=75%, p<.046).

Three studies were included in a meta-analysis of CE (Figures 4 and 5). Again, the studies were subgrouped, according to the age of participants, into adults(15,16) and adolescents(14) and further for FP and AEP. The overall effect size for CE for FP 0.39 [CI -1.09-0.3] indicates that FP NSCLBP patients undershoot into flexion compared to healthy controls. The overall effect size for CE for AEP 0.18 [CI -0.3-0.65] indicates that AEP NSCLBP patients overshoot into extension compared to healthy controls. However, the results are not significant. The adolescent sample in the study by Astfalck and colleagues showed a reverse pattern(14). The heterogeneity of study effects for the FP was considerably (I^2=75%, p<.05). Removing the study of Astfalck and colleagues(14) lowered the heterogeneity considerably (I^2=26%, p=.24). The heterogeneity of study effects for the AEP subgroup was neglectible (I^2=36%, p=.21)

DISCUSSION

The results of this study indicate that lumbar reposition sense is impaired in patients with NSCLBP compared to healthy controls. In the majority of the studies, patients with NSCLBP produced a greater AE and VE than healthy controls. Additionally, patients with FP NSCLBP tend to undershoot into flexion while patients with AEP NSCLBP overshoot into extension. Recent studies tend to report RE for FP and AEP subgroups of NSCLBP patients based on a better and improved understanding of NSCLBP. These studies showed that the direction of RE differs between subgroups. AE and CE tend to show larger effect sizes than VE.

The meta-analysis is based on data of neutral-slumped-neutral sitting[12,14,15,16] because these studies used a comparable measurement procedure and patient criteria. The meta-analysis showed similar findings for adults and adolescents regarding AE and VE.

However study limitations render firm conclusions unsafe. The quality of reporting and the authors' appraisal of risk of bias, in some studies, were limited. Some studies recruited only small samples[12,15,18,20,21,22,23,24,25].

In some studies the inclusion and exclusion criteria were imprecise which however did not affect the studies of the meta-analysis[11,17,20].

It is hypothesised that reduced proprioception is present in the group of CLBP disorders where patients present movement or control impairments[3]. Shortcomings in former studies to screen for this specific group and exclude patients with underlying red flag disorders, specific pathoanatomical disorders and pain disorders with a dominance of non-organic factors may have added to the inconsistency of the findings[17,19,20]. Only five studies reported attempts to minimize selection bias by using matching criteria[12,14,15,17,23].

However within the meta-analysis, studies which included NSCLBP patients with dominant physical factors were included.

The measurement approach varied considerably among studies. Different testing positions, number of repetitions, movement instructions and measurement systems make it difficult to compare findings. Some studies used a warm up phase, practice trials, or demonstrations[11,12,18] while others did not[16,21].

The most frequently used test position was sitting[11,12,15,16,17] The test positions can influence the results of lumbar position sense testing as proprioceptive input may differ depending on which segment of the spine moves (proximal or distal segment) and on the loading of the spine (unloaded vs. loaded). As lumbar RE appears direction specific in FP and AEP NSCLBP populations, the tested movement direction might influence the outcome[14,16,26]. Measurement systems varied and the scale and accuracy of these systems may differ and affect the measurement outcome when measuring small angular differences. The placement of devices/markers varied considerably with some studies assessing the total lumbar spine[12,16,17,21,22,24,25] while others assessed the lower part of the lumbar spine[14,15,18] or larger areas[21,23]. The number of repetitions varied between studies and ranged from 3 to 10[14,17]. The number of repetitions influences the stability of the results.

Several studies reported only one specific aspect of RE, usually AE, which limited the information that could be extracted from these studies[18,19,21,23,24,25]. The definitions of AE, CE, and VE were described rather vaguely in some studies[16,18,20,23]. This hampers comparability, as it is not clear if the same mathematical definition was used for the same type of error.

Recommendations for future research

Future studies, using sufficiently large, matched sample sizes should use adequate screening and diagnostic instruments including the O'Sullivan classification system[35], imagining techniques, response to facet-joint injection and questionnaires such as the STarT Back screening tool[36], the Orebro questionnaire[37] or the Fear-avoidance beliefs questionnaire (FABQ)[38]. Collaboration between allied health and medical professions is required to elucidate the veracity of their hypotheses and for precise patient and control selection.

For future studies we recommend a test position and movement directions that are reported as an aggravating factor by the tested population, such as flexion and extension in sitting for CLBP patients with physical factors[12,15,16]. We further recommend an analysis of criterion validity and between-day reliability of both measurement error and reliability of the measurement device and approach, a standardized and validated placement of the devices and defining the adequate number of repetitions through a D-study[39,40].

We recommend that authors present exact formulas for AE, CE, and VE and suggest the following definitions, with E being the expected error (E) which is equivalent to the mean error in finite populations:

AE is the mean absolute difference between the starting (Θ) and final position (X).

$$AE = E[|X - \Theta|]$$

CE is the mean signed difference between Θ and X.

$$CE = E[X - \Theta]$$

VE is the square root of the error variance.

$$VE = \sqrt{Var([X - \Theta])}$$

We recommend continuing to evaluate various aspects of error (AE, CE, and VE). Other aspects of RE are hardly mentioned in this review. Movement time or velocity[20], learning phase, mean-squared RE, and the relevance of visual or verbal feedback need to be investigated. Further prospective randomized controlled studies (RCT) are needed to assess if improvements in movement control are associated with improvements in proprioception. The association of lumbar RE errors to other movement dysfunctions and other dimensions of LBP should be assessed. In summary only a large, well powered, prospective RCT with a standardized measurement approach can address the hypothesis that proprioception is impaired in CLBP patients with physical factors and treatable through a classification guided intervention.

Limitations of this study

It has been discussed that using a funnel plot should assess publication bias when 10 or more studies can be pooled. As only six studies were included in the meta-analysis, a funnel plot would have been inconclusive regarding publication bias[41]. We considered a factor analysis of elements in the study design that would determine if a study found differences between NSCLBP patients and controls. However, due to the limited number of studies and the great variety in study designs, this was not possible. Therefore, we focused to choose the presented qualitative appraisal of methodological differences and their effect on the study design.

Clinical implication

Clinical measures of RE are being used to assess proprioceptive deficits. The studies included in this review and meta-analysis strengthens the assumption that patients with NSCLBP produce greater RE than healthy controls and, therefore, have proprioceptive deficits compared to healthy controls. So far, only one study has investigated the responsiveness of RE to treatment. This study has shown an improvement in pain and RE after a classification guided intervention[3,26]. Until conclusions can be drawn from larger studies we propose clinical interpretation of RE with caution.

CONCLUSION

Whilst patients appeared to produce a larger lumbar RE compared to healthy controls, study limitations render firm conclusions unsafe. Future studies should pay closer attention to power, precision and reliability of the measurement approach, definition of outcome measures and patient selection. We recommend a large, well powered, prospective randomised control study which uses a standardized measurement approach and definitions for AE, CE, and VE to address the hypothesis that proprioception may be impaired with CLBP.

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Table 1: Study design and subjects.

Origin	NSCLBP			Criteria		Healthy controls			
Study	n	m/f	Age (y)	Inclusion	Exclusion	n	m/f	Age (y)	matching
O'Sullivan, 2013 (15)	15	10/5	31.3 ±10.3	NSCLBP >3months,18-65y, increasing symptoms during prolonged sitting, reduced symptoms during standing and walking	Previous back surgery, neurologic symptoms, ear/visual disturbance, red flags, pregnancy/<6months post-partum	15	10/5	32.1 ±9.2	Age, gender, BMI
Astfalck, 2013 (14)	28	14/14	15.7 ±0.5	NSCLBP >3months, 14-16y, MBI< 28kg/m, mechanically induced pain in area between T12 to gluteal folds, no peripheral pain referral, moderate ongoing LBP (NRS >3, most days of the week)	Specific diagnosis, previous back surgery, neurologic symptoms, pelvic or abdominal pain, lower limb surgery/current injury, pregnancy/<6 months post-partum, not English speaking, inability to assume test posture	28	14/14	15.4 ±0.5	Age, gender, pubertal stage, socio-economic status
Sheeran, 2012 (16)	90	31/59	35 ±10.9	LBP >3months, mechanical basis of disorder, motor control impairment (flexion/active extension pattern)	Red flags, yellow flags, pregnancy/breastfeeding, revious back surgery, ear/vestibular/neurologic dysfunction affecting balance, not able to sit or stand up from a stool unaided	35	13/22	36.0 ±10.3	-
Georgy, 2011 (18)	15	?	40.1 ±6.1	LBP >3months, mechanical dysfunction, NRS >5, lumbar ROM of at least 50% of normal range	Previous inner ear infection or vestibular disorder with balance disturbance, history of head trauma with residual neurological deficits, metabolic diseases, pregnancy/breastfeeding, spinal	15	?	38.5 ±5.9	-

					surgery, severe back pain				
Asell, 2006 [17]	92	45/47	38 ±7	LBP >6months	Diabetes, psychiatric diagnoses, neurologic and rheumatic disorders, dizziness, vestibular disease, surgery last 3 months	31	16/15	36 ±9	Age, gender
Descarreaux, 2005 [20]	16	11/5	41.1	NSLBP >6months	Spondylolosthesis, Spondylolysis, ankylosis spondylitis, osteoarthritis, inflamatory arthritis, nerve root compression, trunk neuromuscular disease, scoliosis (>15°), previous spinal surgery, malignant tumour, hypertension, pregnancy/breastfeeding	15	9/6	38.2	-
O'Sullivan, 2003 [12]	15	6/9	38.8 ±12	Recurrent LBP >3months, diagnosis of lumbar segmental instability flexion pattern	Neurologic involvement, recent back surgery, pain preventing the test, recent motor control rehabilitation, ear/visual disturbance, severe soft tissue tightness around hip/trunk	15	6/9	38.2 ±10.9	Age, height, weight
Koumantakis, 2002 [19]	62	30/32	38.2 ±10.7	Recurrent mechanical NSCLBP with at least 2 episodes within the past year with pain duration of less than half the days in the past year, still working, no neurological condition	trunk or lower limb pathology, deformity, or condition that may affect motor control	18	8/10	24.6 ±4.0	-
Brumagne, 2000 [11]	23	7/16	21.8 ±2.1	Mechanical NSCLBP	Recent history of inner ear infection with associated balance or coordination problem, history of cerebranl trauma with unresolved neurosensory symptoms, vestibular	21	6/15	22.3 ±3.8	-

					disorder, previous spinal surgery, specific balance or stabilization training in the last 6 months, pain medication				
Newcomer, 2000 [21]	20	8/12	39.3 ±11.4	NSCLBP (mechanical, nonradicular) ≥3months, ROM of at least 50% of normal value	Severe pain preventing cooperation with the study, pregnancy and lactation, previous back surgery, current lower extremity problems, radiculopathy, vertebral compression fracture, neurologic deficit, symptoms of vertigo or dizziness	20	7/13	39.1 ±11.3	-
Newcomer, 2000 [22]	20	9/11	44.2 ±10.6	Pain between L1 and the gluteal folds ≥6months, average pain level of 5 of 10 in the preceding week, ROM of at least 50% of normal value	Severe pain preventing cooperation with the study, pregnancy and lactation, previous back surgery, scoliotic curvature greater than 15°, neurologic or current lower extremity problems, lumbar radiculopathy, vertebral compression fracture, symptoms of vertigo or dizziness	20	9/11	39.8 ±12.7	-
Lam, 1999 [24] & Maffey-Ward, 1996 [25]	20	11/9	29 ±5	Mechanical back pain ≥3months	Back pain from a nonmusculoskeletal pathology, neurologic involvement, previous surgery in back/abdomen/chest	10	5/5	23	-
Gill, 1998 [23]	20	7/13	43.3	Chronic mechanical low back pain >12months	Neurologic deficit, psychological component, further medical problems, nerve root pain	20	7/13	32.9	gender

Table 1: Study design and subjects. NSCLBP=non-specific chronic low back pain, LBP=low back pain, n=number of patients, m/f =male/female, BMI=body mass index, y=years, ROM=range of motion

Table 2: test procedure and instrumentation

Study	Movement task [a]	Measurement details	EO/EC	Instrument (I), Sensor position (SP)
O'Sullivan, 2013 [15]	P: Sitting, warming up by performing max trunk flex/ex, 1 practice trial IP: Sitting (90°hips, knees, ankles), arms supinated on thighs, neutral lumbo-pelvic spinal posture, (maintained 5 s) M: Slumped position (maintained 5 s) TP: Initial position (maintained 5 s)	n: 3 rest (s): ? feedback[b]: undergarments, shorts feedback[c]: no	-	I: "Body Guard" (Sels Instruments, Belgium) SP: L3, S2
Astfalck, 2013 [14]	P: Sitting, 3x ROM, 2 practice trials IP: Sitting (90° hips and knees), arms supinated on tighs, mid-range sitting posture position (maintained 5 s) M: Slumped position (maintained 5 s) TP: Initial position	n: 3 rest (s): ? feedback[b]: undergarments, shorts feedback[c]: no	EC	I : "Fastrak" (Polhemus Navigation Sciences Division, Vermont, USA) SP : L3, S2
Sheeran, 2012 [16]	P: Sitting/standing, 3x ROM IP: 1) Sitting, arms loose on thigh; 2) Standing, feed shoulder width apart, neutral lumbar and thoracic mid-range position (maintained 5 s) M: 1) Relaxed usual sitting (maintained 5 s); 2) Relaxed usual standing TP: Initial position	n: 4 rest (s): ? feedback[b]: loose clothing feedback[c]: no	EC	I: Vicon 512 (Vicon Motion Systems Ltd, Oxford, UK) SP: T12, S1
Georgy, 2011 [18]	P: Sitting, stabilized by straps, 3 practical trials IP: Sitting, passively moved to 30° of lumbar flexion (maintained 10 s) M: Upright neutral sitting TP: 30° lumbar flexion (maintained 3 s)	n : 3 rest (s) : 10 feedback[b]: ? feedback[c]: no	-	I: Biodex System 3 Pro Isokinetic Dynamometer (Biodex Medical Inc., Shirley, New York, USA) SP: Axis of actuator arm with L5/S1
Asell, 2006 [17]	P: Sitting, 2x sit-to-stand, 2x ROM, 6 practical trials (3 verbally, 3 pre-recorded instructions) IP: Sitting, hips and knees at 90°, guarded to the target position (maintained 2 s)	n: 10 rest (s): 3 feedback[b]: undergarments, hair in a bun, boldered armpits. No drinking	EC	I : "Fastrak" (Polhemus Navigation Sciences Division, Vermont, USA) SP : T7, S2, midpoint between

	M: Lumbar flexion until auditory signal (90% of max flex S2) TP: 1/3 of the way towards maximal extension from the subjects normal sitting position, verbal signal by subject	or eating 2h prior to testing feedback[c]: no		those 2 segments
Descarreaux, 2005 (20)	P: Standing, Max ROM, learning phase with visual accuracy feedback till 5 consecutive trunk positioning within 10% margin IP: Neutral (0° flex or ex), pelvis and legs immobilised M: Flexion (15°, 30°, 60°), Extension (15°), randomised TP: Flexion (15°, 30°, 60°), Extension (15°), randomised	n: 10 (a 5 s) rest (s): ? feedback[c]: no	-	I: Loredan (Loredan Biomedical, West Sacramento, USA) SP: ?
O'Sullivan, 2003 (12)	P: Sitting, 3 x ROM IP: Sitting (90°hips, knees, ankles), arms relaxed on thighs, neutral spine posture (maintained 5 s) M: Full lumbar flexion (maintained 5 s) TP: Initial position	n: 5 rest (s): ? feedback[b]: undergarments, shorts feedback[c]: no	EC	I : "Fastrak" (Polhemus Navigation Sciences Division, Vermont, USA) SP : T12, L2, L4, S2
Koumantakis, 2002 (19)	P: Standing, practicing with visual feedback IP: Standing, hip leaning against a bench M : Flexion, rotation, side-flexion TP : 20° Flexion,15° rotation, 15° side-flexion	n : 3 within 30s rest (s) : ? feeback[b]: loose clothing, barefoot/flat shoes feedback[c]: no	EC	I: Lumbar Motion Monitor (LMM, Chattecx Corp., Chattanooga, TN, USA) SP : ?
Brumagne, 2000 (11)	P: Standing, 10 x pelvic tilt to warm up, ROM pelvic tilt IP: criterion position varying around neutral (maintained 5 s) M: Anterior pelvic tilt TP: Criterion position	n: 5 rest (s): ? feedback[b]: shorts feedback[c]: no	-	I: electrogoniometer SP: ?
Newcomer, 2000 (21)	P: Standing IP: Standing, feet at shoulder´s width apart and arms at side,1) neutral; 2) 50% max ROM of flexion, extension, rotation, side-flexion M: 1) flexion, extension, rotation, side-flexion; 2) to neutral TP: 1) neutral position (5 s to move to desired position, maintained 2 s) 2) 50% of max ROM of Flexion, extension, rotation, lateral-flexion (5 s	n: 3 rest (s): 2 feedback: ?	EO/EC	I : "Fastrak" (Polhemus Navigation Sciences Division, Vermont, USA) SP : L1, S1

	to move to desired position, maintained 2 s)			
Newcomer, 2000 [22]	P: Standing, feet shoulder-width apart, arms at side, lower extremity and pelvic immobilized, ROM IP: Standing, feet shoulder-width apart, arms at side, lower extremity and pelvic immobilized, neutral M: Flexion, extension, side-flexion (5 s to move to desired position) TP: 30%, 60%, 90% of max ROM (maintained for 2 s)	?	EC	I : “Fastrak” (Polhemus Navigation Sciences Division, Vermont, USA) SP : T1, S1
Lam, 1999 [24] & Maffey-Ward, 1996 [25]	P: Cycling (5 minutes), ROM, 5 practice trials IP: Sitting with hips and knees 90°, neutral upright posture M: Full lumbar flexion (maintained 3 s) TP: Initial position	n: 3 rest (s): 15 feedback: shorts, undergarments, no drinking or eating 2h prior testing	EC	I : “Fastrak” (Polhemus Navigation Science Division, Vermont, USA) SP : T10, S2
Gill, 1998 [23]	P: 10 practical trails with visual feedback from screen IP: 1) Standing: arms crossed; 2) Four-point-kneeling: 90° of hips, knees, shoulders M: Lumbar flexion TP: lumbar flexion 20°	n: 10 within 30 s rest (s): ? feedback[b]: loose clothing	EC	I : Lumbar Motion Monitor (LMM, Chattecx Corp., Chattanooga, TN, USA) SP : Harness, inferior binding posts level of T7

Table 2: test procedure and instrumentation. [a] P=Preparation, IP= Initial Position, M=Movement, TP= Target Position, [b] sensory feedback (clothing, organs), [c] acustic or verbal feedback during measurements. S=seconds, EO/CE=eyes open/eyes closed, C=cervical, T=thoracic, S=sacral, max=maximal, ROM= Range of Motion, n= number of trials

Table 3: outcomes and effect size measures

	Test position	Movement Direction	patients			controls			Effect size		
Absolute error			**mean**	**SD**	**n**	**mean**	**SD**	**n**	**Hedges g/ Cohens r***	**95%CI LL**	**95%CI UL**
O'Sullivan, 2013 (15)	sitting	flexion	11.5	6.4	15	5.1	3.6	15	1.20	0.41	1.99
Astfalck, 2013 (14)	sitting	flexion	4.1	2.3	28	3.1	1.3	28	0.53	-0.01	1.06
Sheeran, 2012 (16)	sitting	flexion	7.7	4.1	90	1.8	.8	35	1.67	1.23	2.11
Georgy, 2011 (18)	sitting	extension	7.5	3.3	15	2.8	.9	15	1.88	1.04	2.72
O'Sullivan, 2003 (12)	sitting	flexion	1.7	.8	15	1.1	.6	15	0.83	0.08	1.58
Lam/Maffey (24, 25)	sitting	flexion	2.3	.9	20	2.6	1.2	10	-0.29	-1.05	0.47
Gill 1998 (23)	standing	flexion	6.7	5.0	20	4.5	3.4	20	.26	-0.12	1.20
Sheeran, 2012 (16)	standing	flexion	6.3	3.7	90	1.9	1.3	35	1.67	1.23	2.11
Koumantakis 2002 (19)	standing	flexion	5.5	3.5	62	3.7	1.8	18	0.55	0.03	1.08
Brumagne, 2000 (11)	standing	extension	4.3	1	23	1.6	.6	21	3.18	2.30	4.06
Constant error											
O'Sullivan, 2013 (15)	sitting	flexion	-6.9	11.5	15	2.6	5.0	15	-1.04	-1.79	-0.30
Astfalck, 2013 (14)	sitting	flexion	- .1	4.2	28	- .8	2.6	28	0.20	-0.32	0.72
Sheeran, 2012 (16)	sitting	flexion	.9	7.7	90	.2	1.1	35	0.11	-0.28	0.49
Brumagne, 2000 (11)	standing	extension	-2.5	2.5	23	-.6	1.0	21	-0.96	-1.58	-0.35
Sheeran, 2012 (16)	standing	flexion	-1.9	5.2	90	-.5	0.9	35	-0.31	-0.70	0.08
Variable error											
O'Sullivan, 2013 (15)	sitting	flexion	4.3	2.4	15	3.6	2.9	15	0.25*	-0.44	0.95
Astfalck, 2013 (14)	sitting	flexion	3.4	2.1	28	2.8	1.6	28	0.32	-0.21	0.84
Sheeran, 2012 (16)	sitting	flexion	4.2	2.6	90	1.9	1	35	1.01	0.60	1.42
Koumantakis 2002 (19)	standing	flexion	2.2	1.6	62	1.7	1.0	18	0.33	-0.19	0.86

Brumagne, 2000 [11]	standing	extension	3.3	1.4	23	1.7	0.7	21	1.40	0.75	2.05
Sheeran, 2012 [16]	standing	flexion	4.2	2.4	90	1.8	1.2	35	1.12	0.70	1.53

Table 3: outcomes and effect size measures * indicates that data was non-normally distributed and Cohens r was calculated as effect size measure.

Table 4. Study quality assessment based on STROBE [32, 33]

STROBE [33]	Item \ Study	Asell [17]	Astfalck [14]	Brumagne [11]	Descarreaux [20]	Georgy [18]	Gill [23]	Koumantakis [19]	Lam [24]	Maffey-Ward [25]	Newcomer [21]	Newcromer [22]	O'Sullivan [15]	O'Sullivan [12]	Sheeran [16]
Title & Abstract	1a	1	0	1	1	1	1	1	1	0	0	0	0	1	1
	1b	0	1	1	0	1	0	1	1	1	0	0	1	1	0
Introduction															
Background	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Objectives	3	1	1	1	1	1	1	1	1	1	0	1	1	1	1
Methods															
Study Design	4	1	0	0	0	1	0	0	0	0	0	0	0	1	0
Setting	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Participants	6a	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	6b	1	1	0	0	0	0	0	0	0	0	0	1	1	1
Variables	7	1	1	0	1	0	0	1	1	0	0	1	1	0	0
Data Sources	8	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Bias	9	1	1	1	0	1	1	1	1	1	0	0	1	1	1
Study Size	10	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Quantitative variables	11	1	1	0	1	0	0	1	0	0	1	1	0	0	1
Statistical Methods	12a	1	1	1	1	1	0	1	1	1	1	1	1	1	1
	12b	1	1	0	1	1	0	0	0	0	1	1	0	0	1
	12c	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	12d	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	12e	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Results															
Participants	13a	0	1	0	1	0	0	0	0	0	0	0	0	0	1
	13b	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	13c	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Descriptive Data	14a	1	1	1	1	1	0	1	0	0	1	1	1	1	1
	14b	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Outcome Data	15	0	1	1	1	1	1	1	1	1	0	0	1	0	1
Main Results	16a	0	1	0	0	0	0	1	0	0	1	0	1	0	0
	16b	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16c	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Discussion															
Other Analysis	17	1	1	0	1	1	1	1	0	0	1	1	0	0	1
Key Result	18	1	1	1	1	1	1	0	1	0	1	1	1	1	1
Limitation	19	1	1	0	0	1	0	0	0	0	0	1	1	1	0
Interpretation y	20	1	1	1	1	1	1	1	1	1	0	1	1	1	1
Generalizabilit	21	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Other Information (Funding)	22	1	1	0	1	0	1	1	0	0	1	0	1	0	1

Table 5. Reliability and Measurement Error

Author	Reliability	Measurement error	Conclusion
Koumantakis 2002 [19]	NSCLBP: all RE-tests ICC= 0.24 to 0.64 AE for flexion and rotation: ICC= 0.76 to 0.80 Other RE-tests: ICC = 0.2 to 0.69	NSCLBP: SEM= 0.45° to 1.34° (large) HC: SEM= 0.45° to 3.90°	Low ICC and high SEM The reliability is low in patients with LBP
Asell 2006 [17]	Only tested in HC and with a slightly modified of the sitting pelvic test VE: ICC= 0.75 CE: ICC =0.86		Reliability is acceptable
Descarreaux 2005 [20]	Not specified	Not specified	
Astfalck 2013 [14]	Refer to Maffey-Ward 1996 & Lam 1999. [24, 25]		This task has previously been shown to have good reliability in adults both with and without LBP [24, 25]
Newcomer 2000a [21]		SEMean= 0.48°	

Newcomer 2000b [22]		SEMean= 0.27°	SEMean decreased compared to the previous study
Lam 1999 [24]	No difference in error magnitude between days	No difference in error magnitude between days	Suggest that either the study group did not have kinaesthetic deficits associated with their condition or that the repositioning test in the sitting position lacks sensitivity
Georgy, 2011 [18]	Not specified	Not specified	
O´Sullivan 2003 [12]	Reliability is only indicated for the measurement device.	Measurement error is only indicated for the measurement device.	Reliability and Measurement Error are not specified for the testing protocol.
O´Sullivan 2013 [15]	ICC > 0.80 for the measurement device [42]	Small measurement error for the measurement device [42]	This device has been shown to have very good reliability and measurement error for the measurement of lumbo-pelvic posture.
Sheeran et al., 2012 [16]	Reliability is only indicated for the measurement device (spinal wheel ICC= 0.95-0.98) [43]		

Table 5. Reliability and Measurement Error NSCLBP= Nonspecific Chronic Low Back Pain, RE=Reposition Error, AE=Absolute Error, CE=Constant Error, VE=Variable Error, HC= Healthy Controls, ICC= Intraclass Correlation Coefficient, SEM= Standard Error of the Measurement, SEMean= Standard Error of the Mean; LBP= Low Back Pain

Figure legends

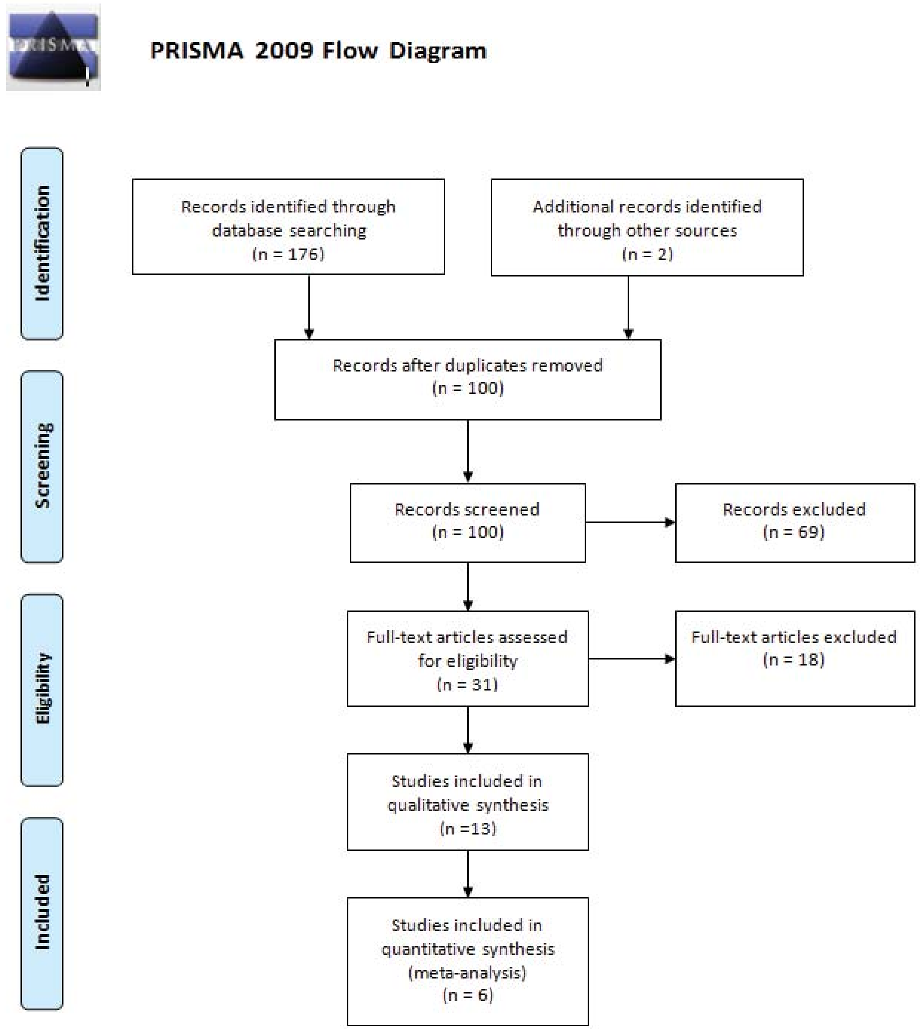
Figure 1. Flow chart according to PRISMA.

Figure 2. Forrest Plot showing the results of the meta-analysis of Absolute Error (AE) subgrouped for adults and adolescents. The overall effect size of 0.81 [CI 0.13-1.49] picture that patients with unspecific low back pain (LBP) have a larger absolute error than healthy controls.

Figure 3. Forrest plot showing the results of the meta-analysis of Variable Error (VE) subgrouped for adults and adolescents. The overall mean difference of 0.57 [CI 0.05-1.09] illustrate that patients with unspecific low back pain (LBP) have a higher deviation of reposition error than healthy controls.

Figure 4 and 5. Forrest Plots showing the results of a meta-analysis on constant error (CE) subgrouped for adults and adolescents. The overall mean difference CE for FP is -0.39 [CI -1.09-0.3] indicates that FP NSCLBP patients undershoot into flexion,. The overall mean difference CE for AEP is 0.18 [CI -.3-0.65] indicates that AEP NSCLBP patients overshoot into extension.

Figures



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *Preferred Reporting Items for Systematic Reviews and Meta-Analyses*: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit www.prisma-statement.org.

Figure 2 (AE)

Study or Subgroup	NSCLBP Mean	NSCLBP SD	NSCLBP Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
2.1.1 Adults								
Sheeran 2012	7.7	4.1	90	1.8	0.8	35	22.3%	1.67 [1.23, 2.11]
O´Sullivan 2003	1.7	0.8	15	1.1	0.6	15	19.0%	0.83 [0.08, 1.58]
Lam/Maffey-Ward 1999/1996	2.3	0.9	20	2.6	1.2	10	18.8%	-0.29 [-1.05, 0.47]
O´Sullivan 2013	11.5	6.4	15	5.1	3.6	15	18.5%	1.20 [0.41, 1.99]
Subtotal (95% CI)			**140**			**75**	**78.6%**	**0.88 [0.02, 1.73]**
Heterogeneity: $Tau^2 = 0.64$; $Chi^2 = 19.64$, $df = 3$ ($P = 0.0002$); $I^2 = 85\%$								
Test for overall effect: $Z = 2.01$ ($P = 0.04$)								
2.1.2 Adolescents								
Astfalck 2013	4.1	2.3	28	3.1	1.3	28	21.4%	0.53 [-0.01, 1.06]
Subtotal (95% CI)			**28**			**28**	**21.4%**	**0.53 [-0.01, 1.06]**
Heterogeneity: Not applicable								
Test for overall effect: $Z = 1.94$ ($P = 0.05$)								
Total (95% CI)			**168**			**103**	**100.0%**	**0.81 [0.13, 1.49]**
Heterogeneity: $Tau^2 = 0.48$; $Chi^2 = 23.13$, $df = 4$ ($P = 0.0001$); $I^2 = 83\%$								
Test for overall effect: $Z = 2.34$ ($P = 0.02$)								
Test for subgroup differences: $Chi^2 = 0.47$, $df = 1$ ($P = 0.49$), $I^2 = 0\%$								

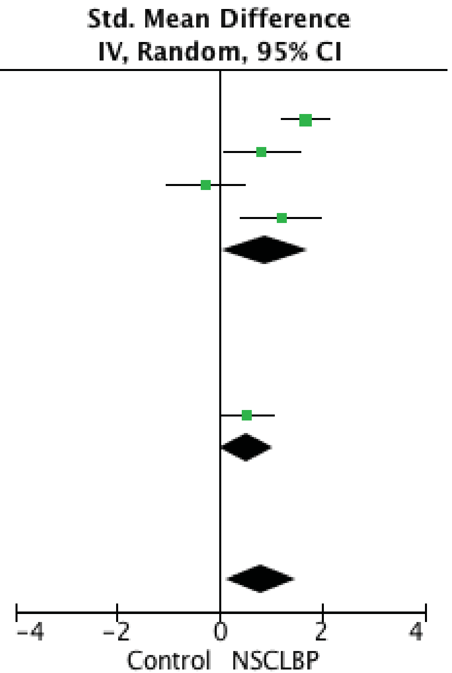


Figure 3 (VE)

	NSCLBP			Control				Std. Mean Difference
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**
3.1.1 Adults								
Sheeran 2012	4.2	2.6	90	1.9	1	35	53.0%	1.01 [0.60, 1.42]
Subtotal (95% CI)			**90**			**35**	**53.0%**	**1.01 [0.60, 1.42]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 4.80 (P < 0.00001)								
3.1.2 Adolescents								
Astfalck 2013	3.4	2.1	28	2.8	1.6	28	47.0%	0.32 [-0.21, 0.84]
Subtotal (95% CI)			**28**			**28**	**47.0%**	**0.32 [-0.21, 0.84]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.18 (P = 0.24)								
Total (95% CI)			**118**			**63**	**100.0%**	**0.68 [0.01, 1.36]**

Heterogeneity: $Tau^2 = 0.18$; $Chi^2 = 4.08$, df = 1 (P = 0.04); $I^2 = 75\%$
Test for overall effect: Z = 1.98 (P = 0.05)
Test for subgroup differences: $Chi^2 = 4.08$, df = 1 (P = 0.04), $I^2 = 75.5\%$

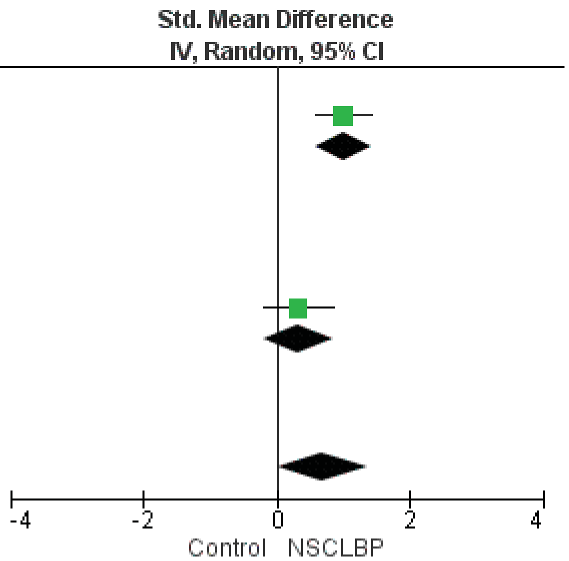


Figure 4 (CE FP)

Study or Subgroup	NSCLBP Mean	NSCLBP SD	NSCLBP Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
4.1.1 Adults								
O´Sullivan 2013 FP	-6.9	11.5	15	2.6	5	15	29.0%	-1.04 [-1.81, -0.27]
Sheeran 2012 FP	-3	6.9	51	-0.2	1.1	35	38.2%	-0.52 [-0.95, -0.08]
Subtotal (95% CI)			**66**			**50**	**67.2%**	**-0.68 [-1.16, -0.20]**
Heterogeneity: $Tau^2 = 0.04$; $Chi^2 = 1.35$, df = 1 (P = 0.24); $I^2 = 26\%$								
Test for overall effect: Z = 2.80 (P = 0.005)								
4.1.2 Adolescents								
Astfalck 2013 FP	0.3	4.5	15	-0.8	2.6	28	32.8%	0.32 [-0.31, 0.95]
Subtotal (95% CI)			**15**			**28**	**32.8%**	**0.32 [-0.31, 0.95]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.99 (P = 0.32)								
Total (95% CI)			**81**			**78**	**100.0%**	**-0.39 [-1.09, 0.30]**
Heterogeneity: $Tau^2 = 0.28$; $Chi^2 = 7.95$, df = 2 (P = 0.02); $I^2 = 75\%$								
Test for overall effect: Z = 1.11 (P = 0.27)								
Test for subgroup differences: $Chi^2 = 6.15$, df = 1 (P = 0.01), $I^2 = 83.7\%$								

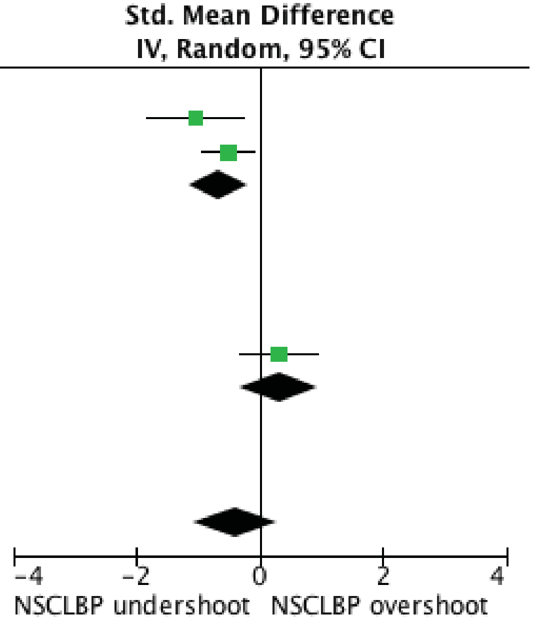
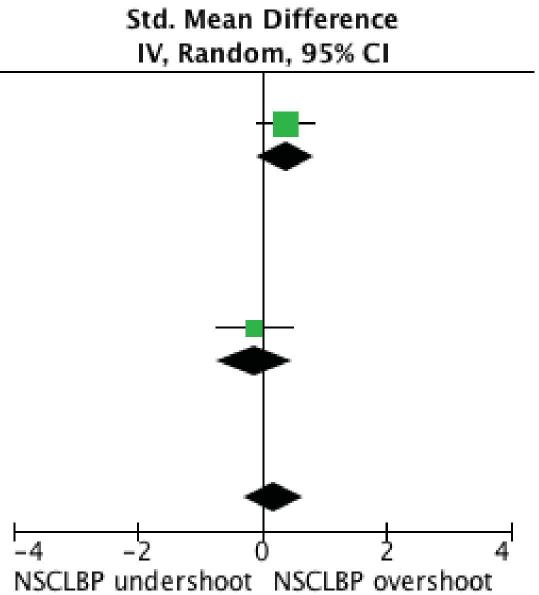


Figure 5 (CE AEP)

Study or Subgroup	NSCLBP Mean	NSCLBP SD	NSCLBP Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
5.1.1 Adults								
Sheeran 2012 AEP	2	7.9	39	−0.2	1.1	35	59.6%	0.38 [−0.08, 0.84]
Subtotal (95% CI)			**39**			**35**	**59.6%**	**0.38 [−0.08, 0.84]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 1.60 (P = 0.11)								
5.1.2 Adolescents								
Astfalck 2013 AEP	−0.6	3.9	15	−0.1	4.2	28	40.4%	−0.12 [−0.75, 0.51]
Subtotal (95% CI)			**15**			**28**	**40.4%**	**−0.12 [−0.75, 0.51]**
Heterogeneity: Not applicable								
Test for overall effect: Z = 0.37 (P = 0.71)								
Total (95% CI)			**54**			**63**	**100.0%**	**0.18 [−0.30, 0.65]**

Heterogeneity: $Tau^2 = 0.04$; $Chi^2 = 1.56$, df = 1 (P = 0.21); $I^2 = 36\%$
Test for overall effect: Z = 0.72 (P = 0.47)
Test for subgroup differences: $Chi^2 = 1.56$, df = 1 (P = 0.21), $I^2 = 35.8\%$



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