Title: The relationship between balance performance, lumbar extension strength, trunk extension endurance, and pain in participants with chronic low back pain, and those without.

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Abstract

Background: Chronic low back pain is associated with lumbar extensor deconditioning. This may contribute to decreased neuromuscular control and balance. However, balance is also influenced by the hip musculature. Thus, the purpose of this study was to examine balance in both asymptomatic participants and those with chronic low back pain, and to examine the relationships among balance, lumbar extension strength, trunk extension endurance, and pain.

Methods: Forty three asymptomatic participants and 21 participants with non-specific chronic low back pain underwent balance testing using the Star Excursion Balance Test, lumbar extension strength, trunk extension endurance, and pain using a visual analogue scale.

Findings: Significant correlations were found between lumbar extension strength and Star Excursion Balance Test scores in the chronic low back pain group (r = 0.439-0.615) and in the asymptomatic group (r = 0.309-0.411). Correlations in the chronic low back pain group were consistently found in posterior directions. Lumbar extension strength explained ~19.3% to ~37.8% of the variance in Star Excursion Balance Test scores for the chronic low back pain group and ~9.5% to ~16.9% for the asymptomatic group.

Interpretation: These results suggest that the lumbar extensors may be an important factor in determining the motor control dysfunctions, such as limited balance, that arise in chronic low back pain. As such, specific strengthening of this musculature may be an approach to aid in reversing these dysfunctions.

Key words: CLBP; Stability; MedX; Star Excursion Balance Test

Introduction

Chronic low back pain (CLBP) is highly prevalent (Freburger, et al., 2009), with considerable direct and indirect costs (Guo, et al., 1999; Maniadakis & Gray, 2000; Ricci, et al., 2006). CLBP can sometimes be attributed to specific pathology (Airaksinen et al., 2006). However, 'non-specific' CLBP accounts for most cases (White & Gordon, 1982) and is not attributable to identifiable pathology. The musculature, intervertebral discs, facet joints, or any structures within the lumbar spine are all possible sources of pain causing mechanisms in non-specific CLBP. In addition to physical complications, CLBP can also lead to psychosocial problems (Linton et al., 2000). As CLBP is often associated with a variety of dysfunctions, many acknowledge it as a multifactorial condition (National Research Council, 1998; National Research Council and the Institute of Medicine, 2001). Indeed, integrated models of dysfunction suggest many of these factors may be related to one another and affect the overall nature of CLBP (Lee & Vleeming, 1998).

Despite the multifactorial nature of CLBP, dysfunction of the neuromuscular system's ability to control specific movement quality and/or create stability (i.e. motor control) is common. Balance is often examined in relation to motor control ability. Indeed, balance may be important for the prevention of injury and CLBP in the first instance (Hammami et al. 2016). Balance is controlled by the neurological, musculoskeletal, proprioceptive, vestibular and visual systems (Ganesh et al., 2015), which allow normal posture to be maintained (Winter et al., 1990; Luoto & Aalto, 1998; Mergner et al., 2005). Good postural control requires an input system for collecting information, an integration system, and an effector system (Luoto & Aalto, 1998). The combination of these allow for a successful response outcome, whereas impairment to one or more of these components may result in poor balance (Oyarzo, et al., 2014).

Although balance requires coordination of the nervous system to respond to stimuli and appropriately recruit the musculature, the musculature itself must also be able to affect such commands. Early work highlighted the importance of the hip musculature in aiding balance (Winter, et al., 1993; Winter, 1995). However, the predominant muscles involved with lumbar stability specifically are the lumbar extensors including the superficial erector spinae (longissimus thoracis and iliocostalis lumborum) and both deep and superficial musculature (i.e. rotators, intertransversi, multifidi) (Panjabi, 1992; Drake et al. 2010).

Deconditioning of the lumbar extensors is a common feature of CLBP (Steele et al., 2014a). In addition to loss of strength and endurance, muscular deconditioning may impact proprioception further compounding balance dysfunction (Kim, et al., 2014). In CLBP patients, coordination of the low back muscles is often reduced (Hodges & Richardson, 1999) in addition to force matching ability (Pranata, et al., 2017). This contributes to decreased control and stability (Gill & Callaghan, 1998; Lam et al., 1999; Della Volpe et al., 2006). Indeed, lumbo-pelvic deconditioning influences the use of hip strategy for control of balance in CLBP perhaps highlighting its importance (Carpes et al., 2008). These adaptations also lead to somatosensory disabilities and over reliability on the visual system for balance (Mergner et al., 2005) due to dysfunction of the peripheral proprioceptive system or the central integration of proprioceptive information (Della Volpe et al., 2006).

Several studies findings also lead to the suggestion that CLBP might lead to altered motor control due to pain-inhibitory mechanisms (Graven-Nielsen, et al., 1997; Gill & Callaghan, 1998; Rossi, et al., 2003; Mense, 1993; Oyarzo et al., 2014). In CLBP hindered activation of the musculature affects spinal stabilisation further complicating postural correction strategies (Hodges, 2001). This pain-induced inhibition causes trunk stabilisation to be more challenging (Wilke, et al., 1995).

Integrated models (Lee & Vleeming, 1998) highlight that pain might affect motor control and vice versa, but also that motor control could be affected by muscular deconditioning. In a study of young male athlete's, trunk extension (TEX) strength (measured using a leg and back dynamometer) was associated with various measures of balance (Hammami et al., 2016). Further research has considered the contributions of hip extension, flexion, and abductor strength, in addition to core endurance in female collegiate athletes highlighting that the former, as opposed to the latter, contributed to improved balance ability in the Star Excursion Balance Test (SEBT; Ambegaonkar, et al., 2014). Thus, components of 'trunk' extension function (including both lumbar and hip extension movement) may be important for balance. In older persons with mobility problems, TEX endurance is also associated with greater balance ability (Suri et al., 2009). However, recent work suggests compound TEX based tasks involving hip extension provide different information regarding lumbo-pelvic function compared with tests where lumbar extension (LEX) strength is measured with hip extension contributions removed through appropriate restraints (LEXConway et al., 2016). Indeed, though lumbar extesor recruitment strategies during TEX endurance testing can vary, hamstring recruitment seems far more reliable and may be the reason for reliable performance in this test (Pitcher et al., 2008). As the specific lumbar extensor deconditioning is associated with CLBP, this musculature may also contribute to motor control deficits (Steele et al., 2014a). This has not been examined with respect to balance, although LEX weakness may affect other motor control tasks, such as lumbar control during gait (Steele et al., 2014b). As such, the aim of the present study was to examine balance in both asymptomatic and participants with CLBP, and to examine the relationships among balance using the SEBT, LEX strength, and TEX endurance in both, and the relationship among SEBT pain in the participants with CLBP, in an attempt to identify what factors might contribute most strongly to balance deficits in CLBP.

Methods

Study Design

A cross-sectional study design was utilised to examine relationships among balance using the SEBT, LEX strength, TEX endurance, and pain in participants with CLBP and asymptomatic participants without CLBP. The study was approved by the Health, Exercise and Sport Science Ethics Committee at the lead author's institution (ID No. 363).

Participants

Sample size was estimated for a correlation coefficient of $r = 0.450$ considering other studies examining similar variables in relation the motor control based tasks (Suri et al., 2009; Ambegaonkar et al., 2014; Steele et al., 2014b). Values for α and β were defined as 0.05 and 0.80 respectively. Calculations suggested ~36 participants were required (Hulley, et al., 2013). Attempts were made to recruit ~50% percent more participants to account for attrition between tests and as the estimate was considered to be liberal. As a convenience study, participants were recruited from university staff and students via word of mouth, and both online and poster advertisement.

Inclusion criteria for participants with CLBP were: individuals suffering from non-specific CLBP ($\geq$12 weeks duration) with no medical conditions that would be affected by the testing. Exclusion criteria for participants with CLBP were: individuals with prior lumbar surgery or a medical condition for which movement therapy would be contraindicated. These included: acute (not re-occurring) low back injury occurring within the last 12 weeks, pregnancy, evidence of sciatic nerve root compression (sciatica), lower limb pain radiating to below the knee, paraesthesia (tingling or numbness), current tension sign, lower limb motor deficit, current disc herniation, previous vertebral fractures or other major structural abnormalities, or any contraindications identified in the physical activity readiness questionnaire (PAR-Q) completed. All participants were cleared prior to involvement in the study by either their general practitioner, physiotherapist, or a chiropractor in the research group. For the asymptomatic group the following exlusion criteria applied: back pain exceeding one week in the past year, prior lumbar surgery, or any contraindications identified in the PAR-Q completed.

All participants were provided with a participant information sheet, provided written informed consent and completed a PAR-Q. Forty three asymptomatic participants (18 females, 25 males, ratio 0.72:1.0) and 21 participants with non-specific CLBP (9 females, 12 males, ratio 0.75:1.0) were recruited and completed the study. Participant characteristics are shown in Table 1.

Equipment

Stature was measured using a stadiometer (Holtan ltd, Crymych, Dyfed) and body mass measured using scales (SECA, Germany). Isometric LEX strength and range of motion (RoM) were measured using the MedX (Ocala, Florida) LEX machine (Figure 1). This device is reliable in assessing isometric strength at repeated angles in symptomatic (Robinson et al., 1992) and asymptomatic participants (Graves et al., 1990) and valid in measurement (Inanami, 1991; Pollock, et al., 1991). TEX endurance was measured using the Biering-Sorenson test (Figure 1) which is reliable in both symptomatic and asymptomatic participants (Latimer, et al., 1999; Pitcher et al., 2008). A horizontally-oriented 100mm visual analogue scale (VAS) was used to measure pain within the CLBP group which is also reliable (Ogon et al., 1996). The Oswestry Disability Index (ODI) was used to measure pain-related disability (Gronbald, et al., 1993) and is a valid and reliable measure of CLBP specific disability (Fairbank & Pynsent, 2000). Balance was measured using the SEBT (Figure 1), a dynamic balance test which challenged participant's limits of stability (Olmsted, et al., 2002) and which is commonly used within CLBP studies (Ganesh et al., 2014, 2015). The SEBT is also reliable (Kinzey and Armstrong, 1998; Hertel et al., 2000).

Testing

Participants attended testing on two occasions separated by at least 72 hours to allow recovery from any fatigue or soreness from the testing. During the first visit, anthropometric data were collected and participants with CLBP completed the VAS and ODI. Participants then completed TEX endurance testing using the Biering-Sorenson, and a familiarisation session was conducted to ensure reliable results with the MedX LEX machine (Graves et al., 1990). On the second visit, participants completed the SEBT followed by the LEX strength test in order to avoid any effects upon the SEBT from acute fatigue induced by the LEX strength test. Each test was conducted by the same tester for each participant.

Both the Biering-Sorenson TEX test and LEX strength test protocols have been detailed fully previously (Conway et al., 2016). Briefly, the Biering-Sorenson TEX test involved participants positioned prone on a treatment couch with the upper edge of the iliac crests aligned with the edge of the couch and the lower body fixed to the couch by two straps. Participants were instructed to place their arms diagonally across their chest, raise their torso, and to maintain a neutral position for as long as possible. The time this could be held for was measured using a stopwatch. Test termination occurred with excessive fatigue resulting in downward sloping of the trunk by more than 10° (as observed by visual inspection), unendurable pain, or when 240 seconds was reached. LEX testing involved participants performing a light dynamic warmup followed by maximal isometric tests at various angles throughout their RoM (0, 12, 24, 36, 48, 60, 72). Participants were instructed to gradually build to a maximal effort over 3 seconds. Between each angle 10 second rest was provided involving unloaded flexion/extension.

For the SEBT, stance lower limb was measured from the anterior superior iliac spine to the middle of the medial malleolus using a tape measure. This allowed reach distances to be normalised to lower limb length (Gribble & Hertel, 2003). The task was explained by visual demonstration and verbal instruction and participants completed 6 practice trials in each direction to decrease learning effects (Gribble, 2003). Two minutes recovery was provided between practice and test trials. The SEBT was created by marking the floor with masking tape with 8 lines from a centre point at 45º from each other. Participants placed their stance lower limb in the centre so that equal halves of the foot were in anterior and posterior halves. Participants were instructed to reach maximally with their opposite lower limb in each direction, lightly touch the floor with the most distal part of the foot, and successfully return to standing without additional touchdowns or disturbance of the base of support. The tester marked where the participants touched the lines with a marker pen and these were measured after the trial was completed (tape was replaced with each new test and participant). Successful trials required participant's hands remaining on hips, stance lower limb foot had to remain in its original position, heel of the stance lower limb had stay in contact with the floor, and a light contact made without loss of balance (Robinson & Gribble, 2008). If this was not met the direction was reattempted. This was repeated, alternating lower limbs, until 3 trials were completed on each.

Statistical Analysis

LEX strength was measured in ft·lbs and converted to Nm using a correction of 1.356. A 'strength index' was calculated as the area under the curve for all angles tested by the device software using the trapezoidal method, thus incorporating strength across all tested angles. For the SEBT the mean of the three attempts of each direction was calculated (Robinson & Gribble, 2008). A Shapiro-Wilk test was used to examine assumptions of normality of distribution across the groups for each demographic and dependent variable. The majority of data met assumptions of normality of distribution and so parametric analyses were performed. Pearson's correlation was calculated to examine correlations between SEBT scores for all directions and the average across all directions for both left and right lower limbs independently, as well as the average across all directions for both lower limbs combined, with LEX strength, TEX endurance, and VAS. Correlations were examined within both the participants with CLBP group and the asymptomatic participants group. Correlation coefficients were interpreted as low (r = 0.30-0.50), moderate (r = 0.50-0.70), or high (r > 0.70). Variance explained was examined using R^2. Statistical analysis was performed using the IBM Statistical Package for the Social Science computer package version 22.0 (SPSS, Inc) and $p < .05$ set as the limit for statistical significance.

Results

Table 2 shows the correlation matrix for the participants with CLBP for all variables. Table 3 shows the correlation matrix for the asymptomatic participants for all variables. Significant correlations are reported below.

LEX Strength and Balance

For the participants with CLBP, significant correlations ranging from low to moderate were found for all posterior directions in both the left (*r* = 0.464-0.571, *p* = 0.030-0.006) and right lower limbs (*r* = 0.439-0.615, *p* = 0.041-0.002). A significant moderate correlation was also found for the average across all directions in the right lower limb (*r* = 0.507, *p* = 0.016), but not the left lower limb (*r* = 0.407, *p* = 0.060), and a significant low correlation for average across all directions for both lower limbs combined (*r* = 0.462, *p* = 0.030). Figure 2a shows scatter plots for LEX strength and the average across all directions for the left and right lower limbs, and combined lower limbs.

For the asymptomatic, significant low correlations were found for most posterior directions in the left lower limb (*r* = 0.340-0.411, *p* = 0.028-0.007) and all in right lower limb (*r* = 0.388-0.411, *p* = 0.011-0.007). Significant low correlations were found for most anterior directions in the right lower limb only (*r* = 0.309-0.399, *p* = 0.047, 0.011), and also medial and lateral directions in the right lower limb (*r* = 0.403, *p* = 0.008 and *r* = 0.320, *p* = 0.039 respectively), but only the medial direction for the left lower limb (*r* = 0.324, *p* = 0.036). Figure 2b shows scatter plots for LEX strength and the average across all directions for the left and right lower limbs, and combined lower limbs.

R^2 values suggested that LEX strength explained ~19.3% to ~37.8% of the variance in SEBT scores for the CLBP group. For the asymptomatic group LEX strength explained ~9.5% to ~16.9% of the variance in SEBT scores.

TEX Endurance and Balance

There were no significant correlations between TEX endurance and any SEBT measures in either the participants with CLBP or the asymptomatic participants. Figure 3a & 3b shows scatter plots for LEX strength and the average across all directions for the left and right lower limbs, and combined lower limbs for the participants with CLBP or the asymptomatic participants respectively.

Pain and Balance

There were no significant correlations between VAS and any SEBT measures in the participants with CLBP. Figure 4 shows scatter plots for LEX strength and the average across all directions for the left and right lower limbs, and combined lower limbs for the participants with CLBP.

Discussion

The aim of this study was to examine the relationships among balance using the SEBT, LEX strength, TEX endurance, and pain. All may contribute to motor control function and thus may affect balance ability. The present study revealed LEX strength was associated with SEBT performance for both asymptomatic and participants with CLBP. Correlations were stronger in participants with CLBP and consistently in posterior directions. Variance in SEBT scores were more strongly explained by LEX strength within the CLBP group. Neither TEX endurance (in both groups) nor pain (in the CLBP group) was correlated with SEBT scores.

Both LEX strength and TEX endurance were descriptively lower in participants with CLBP suggesting deconditioning was present (Steele et al., 2014a). Similarly, SEBT scores were also descriptively lower in participants with CLBP similarly to other studies of balance in CLBP (Ganesh et al., 2015; Brumagne, et al., 2008; Mann et al., 2010; Mientjes & Frank, 1999). Prior work found relationships between strength and endurance measures involving hip function and balance in asymptomatic athletic populations (Suri et al., 2009; Ambegaonkar et al., 2014; Hammami et al., 2016). However, in the present study, neither asymptomatic participants, nor participants with CLBP demonstrated relationships between TEX endurance and any SEBT measures. This is despite TEX endurance involving predominantly hip extension (Steele et al., 2014a; Conway, et al., 2016). Deconditioning of the lumbo-pelvic region may influence the use of hip strategy for control of balance in CLBP (Carpes, et al., 2008), which may result in strengthening of the trunk, hip and ankle musculature (Mann et al., 2010). SEBT performance is affected by ankle stability (Kinzey & Armstrong 1998; Olmsted et al., 2002), knee stability (Hertel et al., 2006) and fatigue (Denegar et al., 2001). Indeed the SEBT is often used to test for ankle (Olmsted et al., 2002) and knee stability (Hertel et al., 2006). Therefore, conditioning of the ankle and knee that occurs due to the use of a hip strategy may have aided SEBT performance. Future work may therefore also include other lower body tests to examine their relationships with SEBT in participants with CLBP.

In contrast to the lack of relationships between TEX and SEBT scores, LEX strength was significantly associated with balance in both asymptomatic and participants with CLBP, albeit more strongly in the participants with CLBP. Links between LEX strength and SEBT might be expected as the lumbar musculature plays a key role in spinal stabilisation (Panjabi, 1992; Drake et al., 2010). Indeed it has been hypothesised that many physical dysfunctions in CLBP may result from deconditioning of this musculature (Steele et al., 2014a). Relationships between LEX strength and other motor control tasks have also been reported (Steele et al., 2014b). Other work suggests muscle strengthening is effective for reducing pain and risk of falls (Cassilhas et al., 2007; de Vreede et al., 2007; Hayden et al., 2005; Lange et al., 2008; Sherrington et al., 2011; Steele, et al., 2015a). Improved strength may aid balance by increasing muscle stiffness. This, in turn, may increase neuromuscular control due to improved proprioception and reduced delay from muscle spindle stretch reflex (Blackburn et al., 2000; Hammami et al., 2016). Improvements in motor control and balance may be greater when specific muscular conditioning is performed with balance training (Gillespie et al., 2012). However, balance training in addition to traditional trunk based strengthening exercies may further increase strength in persons with CLBP (Ganesh et al., 2014). Indeed, Suri et al., (2011) reported improvements in TEX endurance were associated with clinically important improvements in balance. However, it has also been shown that specific lumbar extensor strengthening using LEX resistance training improves lumbar motor control during gait (Steele, et al., 2016). As such, the lumbar extensors may play a role in motor control of the lumbar spine, particularly in CLBP, compared with the hip extensors which may play a lesser role.

There may be other explanations for the observed relationships. Lower SEBT scores may result from altered proprioception in participants with CLBP (Gill & Callaghan, 1998; Brummage et al., 2008a; Brumagne, et al., 2008; Mjentjes & Frank, 1999; Oyarzo et al. 2014). Structural and functional changes within brains of persons with chronic musculoskeletal pain can contribute to the chronic pain state and may affect grey matter and cognitive ability (Seminowicz et al., 2011) affecting cortical representations of the body. Indeed, as noted, motor control may be limited due to pain-inhibition mechanisms (Graven-Nielsen et al., 1997; Gill & Callaghan, 1998; Rossi et al., 2003; Mense, 1993; Oyarzo et al., 2014). Participants with CLBP demonstrate proprioceptive deficits (Gill & Callaghan, 1998; Brummage et al., 2008a) and perform poorly on tasks requiring directional judgement of trunk rotation (Bray & Mosely, 2009). Balance dysfunctions in CLBP may be due to altered proprioceptive feedback from the lumbar spine (Gill & Callaghan, 1998) which may be due to dysfunction of the central integration of proprioceptive information affecting mechanoreceptors (Yamashita et al., 1990). Impairment of mechanoreceptors leads to inaccuracy of information necessary for maintenance of dynamic balance (Schmidt & Lee, 2005). In the present study the CLBP group had inferior SEBT scores compared to the asymptomatic group perhaps due to sensory dysfunction. However, there was no relationship between VAS and any of the SEBT scores. Further, it might be expected that the above mechanisms would also affect other functional tests (i.e. TEX endurance) yet there was no such relationships perhaps further supporting that the lumbar extensors specifically may be important for balance in CLBP.

Another explanation could be attributed to accommodation behaviours or pain avoidance behaviours (Al-Obaidi et al., 2000) within the CLBP group. Participants with CLBP develop a fear of pain, catalysed by anticipation of pain rather than sensory experience of pain, which may result in functional disability (Waddel et al., 1993). Participants anticipating pain perform activities less vigorously or may avoid activity as a whole. Thus participants with CLBP may have given sub-maximal effort in the present study. Avoidance behaviour can result in inactivity which has been argued to lead to complications, such as deconditioning, which in hand may lead to the development of CLBP, though this relationship may be bidirectional (Steele et al., 2014a).

Dysfunction to either somatosensory, vestibular or visual inputs may also be possible explanations (Ganesh et al., 2015). During the SEBT, information is constantly relayed to maintain balance. The feedback control circuit between the brain and the musculoskeletal system involves integration of efferent and afferent signals (Lephart et al., 2000). CLBP modifies sensory input to postural control (Gill & Callaghan, 1998). Thus, if afferent input is inaccurate balance may be affected. Since afferent information informs conscious awareness of body and joint position and movement, this may explain balance impairment in CLBP (Guskiewicz & Perrin, 1996). If pain affects information-processing delays to the motor response system may occur (Mense, 1993). For the SEBT, a dynamic task, visual and vestibular inputs are imperative. This is closely linked with the visual system influencing eye movement patterns which, through postural reflexes, affect postural control (Guskiewicz & Perrin, 1996; Lephart et al., 2000).

Participants with CLBP in the present study demonstrated consistent relationships between LEXLEX strength and all posterior directions in the SEBT, whereas asymptomatic participants presented no consistent directional results. Participants with CLBP are more reliant on visual inputs (Mergner et al, 2005), therefore when visual cues are inconsistent, such as during posterior reach directions of the SEBT, the vestibular system becomes predominant for balance (Guskiewicz & Perrin, 1996). Further, the lumbar extensors are involved considerably when reaching in posterior directions (Ganesh et al., 2014). Thus, there is a plausible mechanism whereby greater LEX strength may affect balance during posterior reach directions. For all posterior directions participants with CLBP had lower SEBT scores compared with asymptomatic participants. Reduced excursion distance in the CLBP group would be expected due to combined reduction in proprioceptive feedback and lack of visual cues. This could have resulted in accommodation behaviour, resulting in a reduced posterior reach within symptomatic participants to ensure balance is maintained.

R^2 values indicate the independent variables examined only accounted for a small degree of variance in asymptomatic participants (~9.5% to ~16.9%), whereas this was higher in participants with CLBP (~19.3% to ~37.8%). This suggests that, although LEX strength may be a greater determinant of balance in participants with CLBP, a large proportion of variance in scores may be accounted for by unexamined variables. As noted, these might include proprioceptive ability (Gill & Callaghan, 1998), ankle (Olmsted et al., 2002) and knee stability (Hertel, et al., 2006), or coping strategies (Al-Obaidi et al., 2000). Future work might look at further tests of function and both cognitive and psychosocial components to better understand predominant factors responsible for motor control deficits in CLBP.

These results suggest interventions to strengthen the lumbar extensors in CLBP may useful for balance. Muscle-strengthening based interventions decrease pain and risk of falls (Cassilhas et al., 2007; de Vreede et al., 2007; Hayden et al., 2005; Lange et al., 2008; Sherrington et al., 2011; Steele, et al., 2015a). LEX based exercise may be optimal for lumbar extensor conditioning (Steele, et al., 2015b). Increased LEX strength correlates with reduced pain and disability (Nelson et al., 1995; Steele et al., 2013) and reduces risk of injury (Mooney, et al., 1995; Matheson & Mooney, 1993). Balance training may improve efficacy of strength training (Hammami et al.,2016). Thus strength and balance training may be complimentary.

Conclusion

This study examined relationships between balance performance, LEX strength, TEX endurance, and pain in participants with CLBP, and those without. LEX strength, but not TEX endurance or pain, was associated with SEBT performance. These results suggest the lumbar extensors may be important in determining motor control dysfunctions in CLBP. Further, specific lumbar extensor strengthening may aid in reversing these dysfunctions. As such, future work should examine LEX based strengthening interventions upon balance in CLBP, either alone or in combination with motor control training.

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Figure Legends

FIGURE 1. A) MedX Lumbar Extension Machine used for LEX strength, B) Biering-Sorenson test schematic used for TEX endurance, and C) SEBT test schematic used for balance

FIGURE 2. Scatter plots of SEBT scores (top = left leg, middle = right leg, bottom = combined legs) and LEX strength for A) CLBP participants, and B) healthy asymptomatic participants.

FIGURE 3. Scatter plots of SEBT scores (top = left leg, middle = right leg, bottom = combined legs) and TEX endurance for A) CLBP participants, and B) healthy asymptomatic participants.

FIGURE 4. Scatter plots of SEBT scores (top = left leg, middle = right leg, bottom = combined legs) and VAS for CLBP participants.

Table 1. Participant Demographics

	CLBP (N=13)		Non-CLBP (N=34)	
Variable	Mean ± SD	Range	Mean ± SD	Range
Age (years)	28±12	19-54	30±12	19-57
Stature (cm)	172.9±9.6	155-188	173.4±10.4	155-194
Body Mass (kg)	75.0±12.8	47.5-99.2	74.5±12.5	52.5-99
BMI (kg.m²)	25.0±3.1	19.8-31.3	24.7±3.4	20.0-35.0
SBP (mmHg)	133.8±13.7	111.0-159.0	133.5±15.1	91.0-156.0
DBP (mmHg)	75.5±10.0	62.0-91.0	74.0±9.6	52.0-92.0
VAS (mm)	35.0±23.2	1-73	N/A	N/A
ODI (pts)	22.9±11.9	4-60	N/A	N/A
ROM (^{O})	68.1±6.2	48.0-72.0	68.3±5.1	54.0-72.0
LEX Strength Index (Nm)	12898.7±5427.3	4158.9-25026.3	14892.5±5951.3	6088.4-30.116.8
TEX Endurance (seconds)	115.0±57.5	29.0-240.0	135.7±46.3	51.0-240.0
Left Lower limb Average SEBT (%)	78.4±10.3	60.59-93.58	110.1±17.3	66.32-156.5
Right Lower limb Average SEBT (%)	78.9±9.8	62.2-94.1	86.9±17.9	58.1-156.4
Combined Lower limbs Average SEBT (%)	78.6±10.0	61.4-92.7	98.5±15.3	67.5-156.5

BMI= Body Mass Index; SBP= Systolic Blood Pressure; DBP= Diastolic Blood Pressure; VAS= Visual Analogue Scale; ODI= Oswestry Disability Index; ROM = Range of Motion; LEX = Isolated Lumbar Extension; TEX = Trunk Extension; SEBT = Star Excursion Balance Test

Table 2. Correlations between SEBT scores, and LEX strength, TEX Endurance, and VAS for CLBP participants.

Lower Limb	SEBT Direction	LEX Strength	TEX Endurance	VAS
Left	Anterior	0.287	0.049	-0.013
	Posterior	0.464*	0.197	-0.005
	Medial	0.212	0.060	-0.137
	Lateral	0.291	0.300	0.048
	Anterolateral	0.240	0.025	0.135
	Anteromedial	0.079	0.030	-0.087
	Posterolateral	0.571**	0.196	0.094
	Posteromedial	0.513*	0.200	0.090
	Average	0.407	0.191	-0.026
Right	Anterior	0.361	0.100	0.003
	Posterior	0.615**	0.111	-0.118
	Medial	0.292	0.045	-0.193
	Lateral	0.377	0.276	-0.115
	Anterolateral	0.299	0.219	0.009
	Anteromedial	0.240	0.023	-0.281
	Posterolateral	0.566**	0.164	-0.007
	Posteromedial	0.439*	0.120	-0.172
	Average	0.507*	0.167	-0.145
Combined Lower limbs Average		0.462*	0.181	-0.086

Indicates a significant correlation coefficient at >0.05 level (two-tailed) *

Indicates a significant correlation coefficient at >0.05 level (two-tailed)**

LEX = Lumbar Extension; TEX = Trunk Extension; SEBT = Star Excursion Balance Test

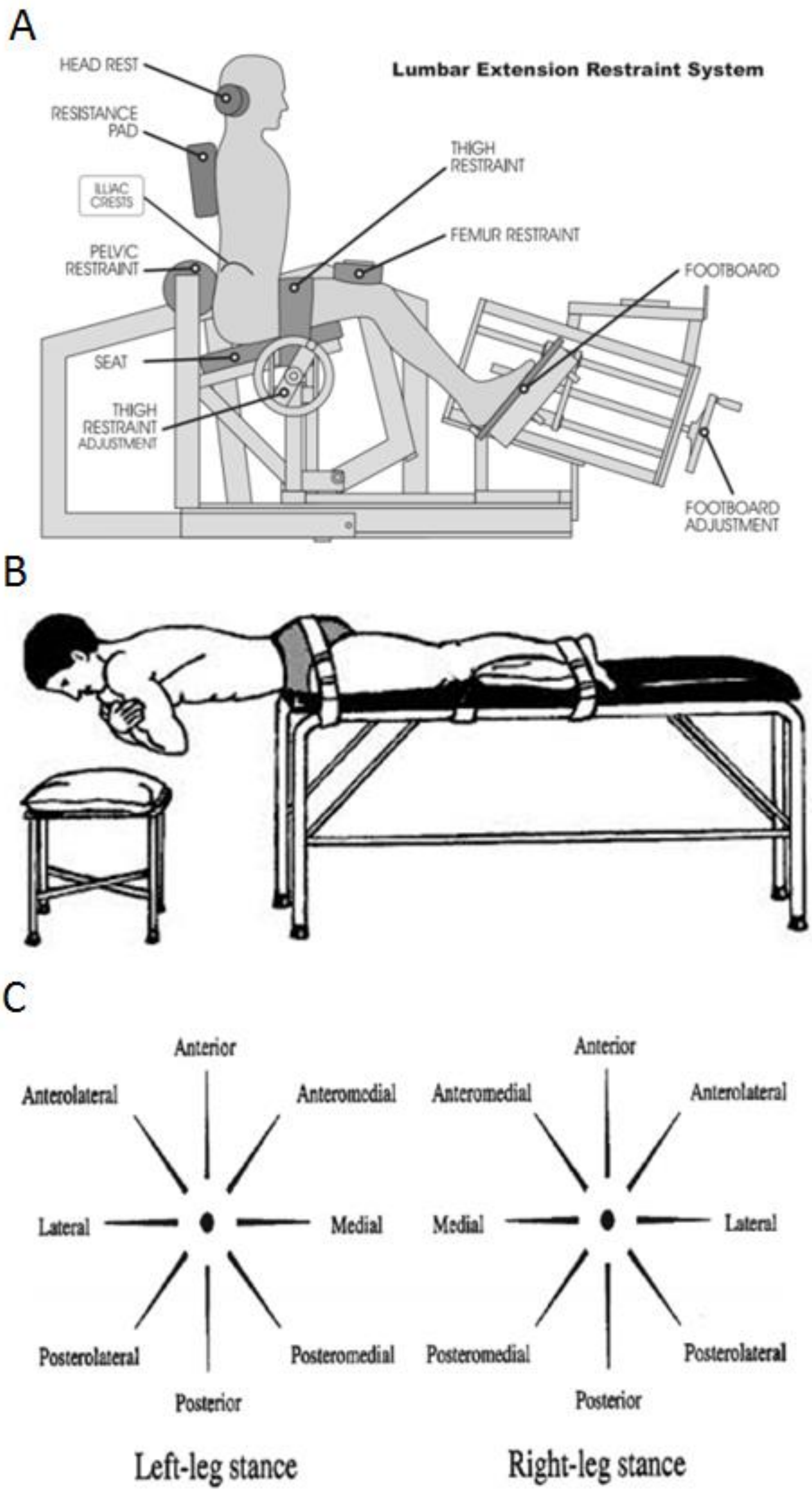
Table 3. Correlations between SEBT scores, and LEX strength, and TEX endurance for healthy asymptomatic participants.

Lower Limb	SEBT Direction	LEX Strength	TEX Endurance
	Anterior	0.196	0.021
	Posterior	0.340*	0.214
	Medial	0.324*	0.207
	Lateral	0.301	0.216
Left	Anterolateral	0.045	0.010
	Anteromedial	0.287	0.099
	Posterolateral	0.270	0.130
	Posteromedial	0.411*	0.234
	Average	0.153	0.304
	Anterior	0.309*	-0.031
	Posterior	0.396**	0.041
	Medial	0.403**	0.127
	Lateral	0.320*	0.102
Right	Anterolateral	0.097	-0.033
	Anteromedial	0.399**	0.103
	Posterolateral	0.388*	0.048
	Posteromedial	0.411**	0.122
	Average	0.153	0.168
Combined Lower limbs Average		0.178	0.270

Indicates a significant correlation coefficient at >0.05 level (two-tailed) *

Indicates a significant correlation coefficient at >0.05 level (two-tailed)**

LEX = Lumbar Extension; TEX = Trunk Extension; SEBT = Star Excursion Balance Test


A
Lumbar Extension Restraint System
HEAD REST
RESISTANCE PAD
ILIAC CRESTS
PELVIC RESTRAINT
SEAT
THIGH RESTRAINT ADJUSTMENT
THIGH RESTRAINT
FEMUR RESTRAINT
FOOTBOARD
FOOTBOARD ADJUSTMENT
B
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Anterior
Anterolateral
Anteromedial
Lateral
Medial
Posterolateral
Posteromedial
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Left-leg stance
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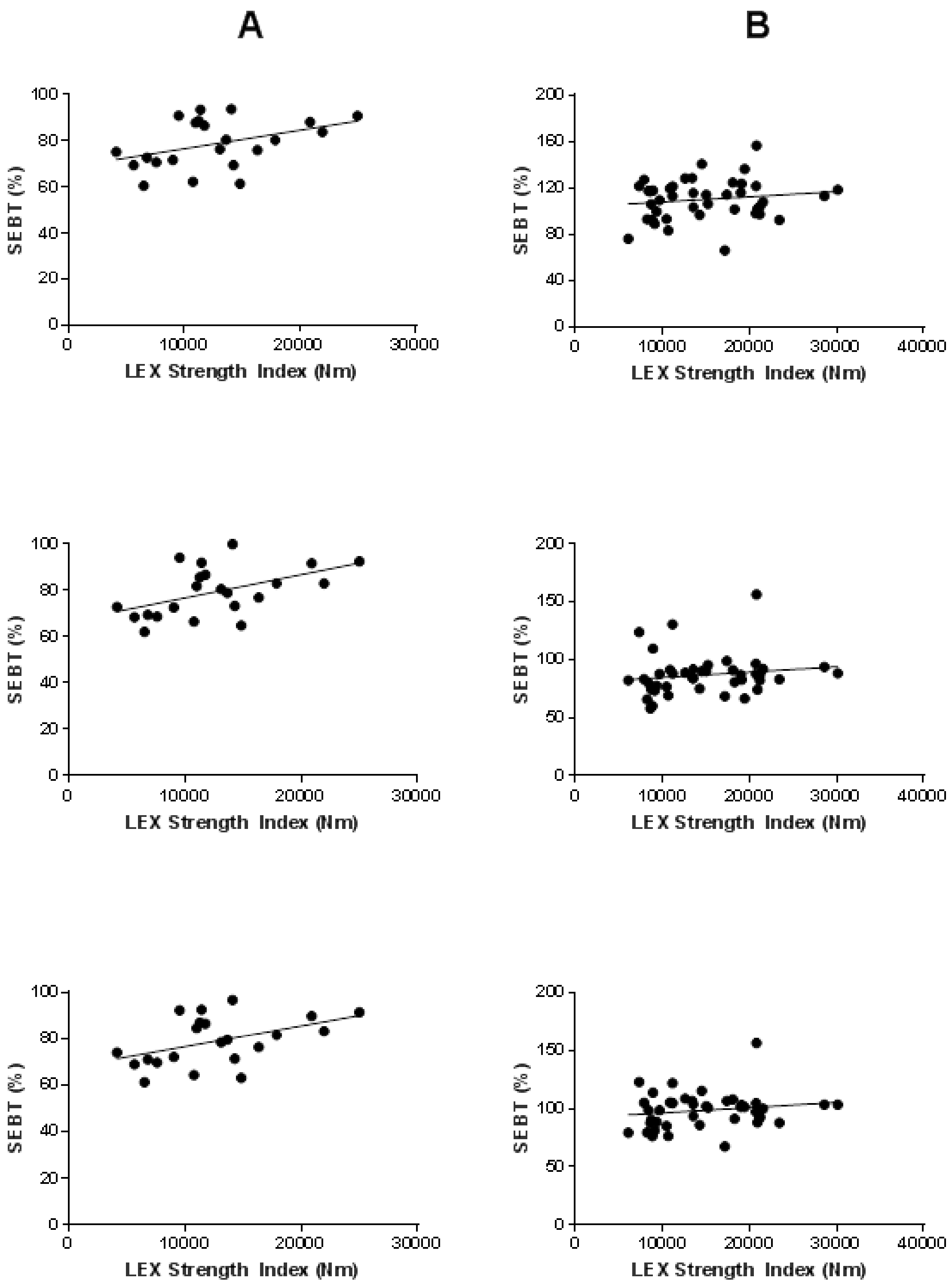
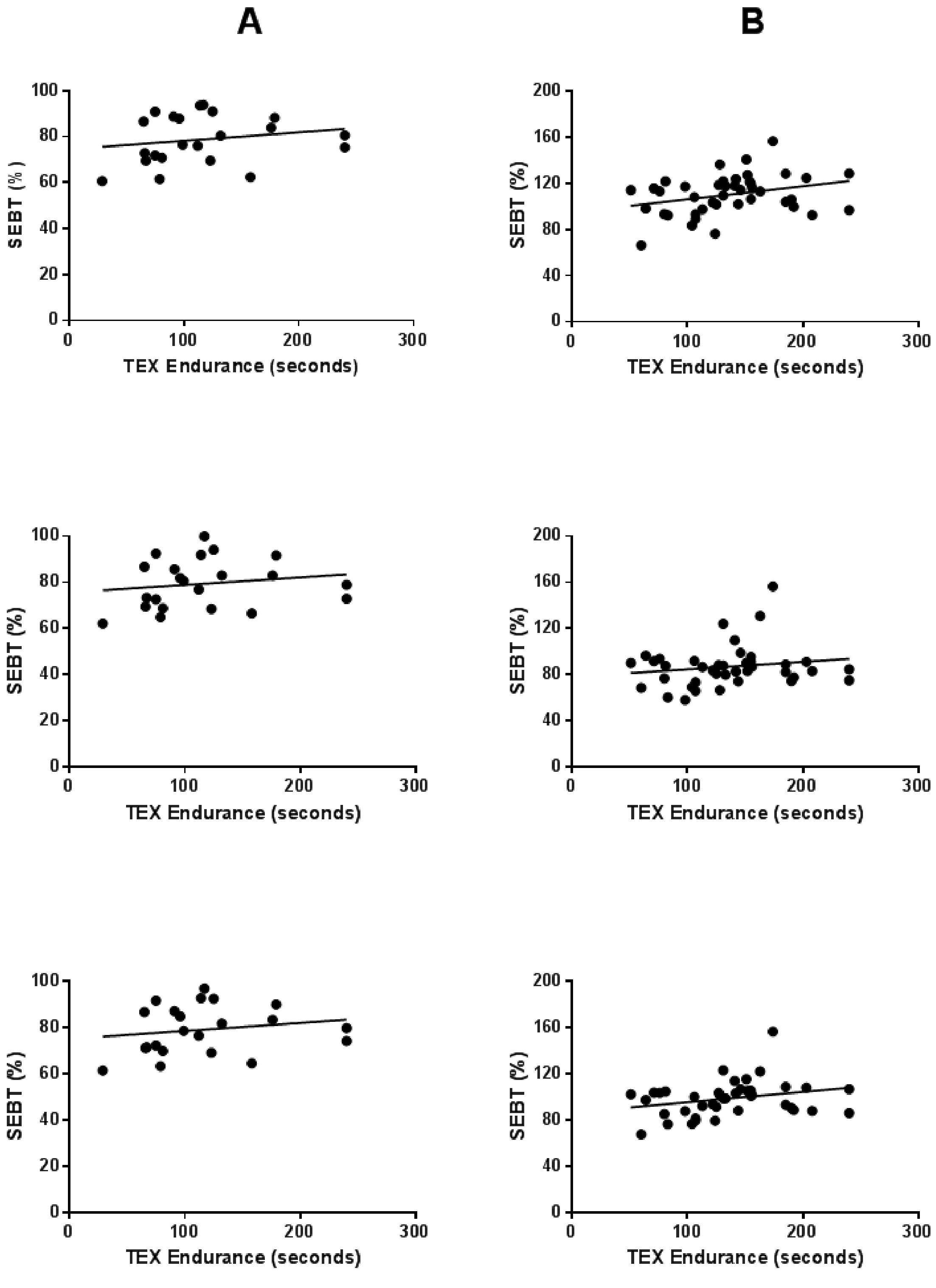
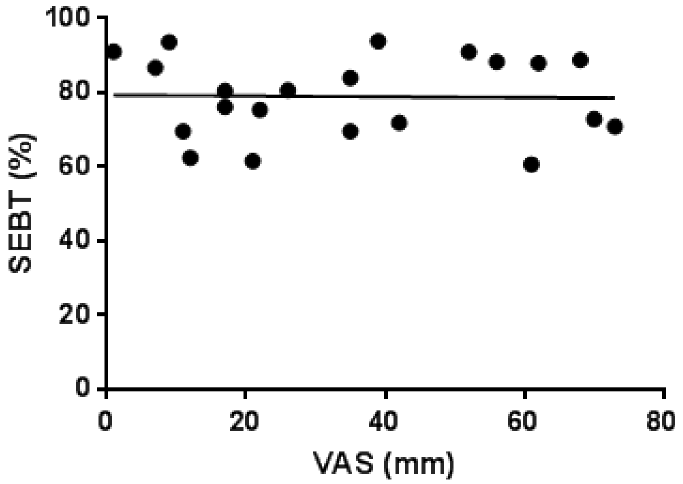
Anterolateral
Medial
Lateral
Posteromedial
Posterolateral
Posterior
Right-leg stance


A
B
SEBT (%)
LEX Strength Index (Nm)


A
B
SEBT (%)
TEX Endurance (seconds)
0
100
200
300
20
40
60
80
120
160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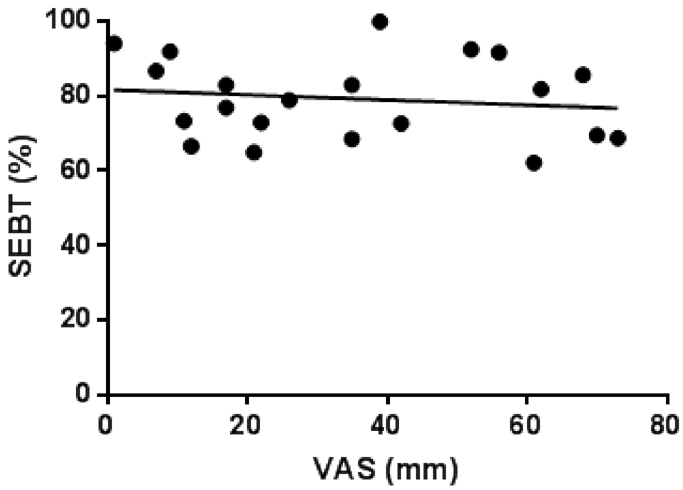
VAS (mm)


SEBT (%)
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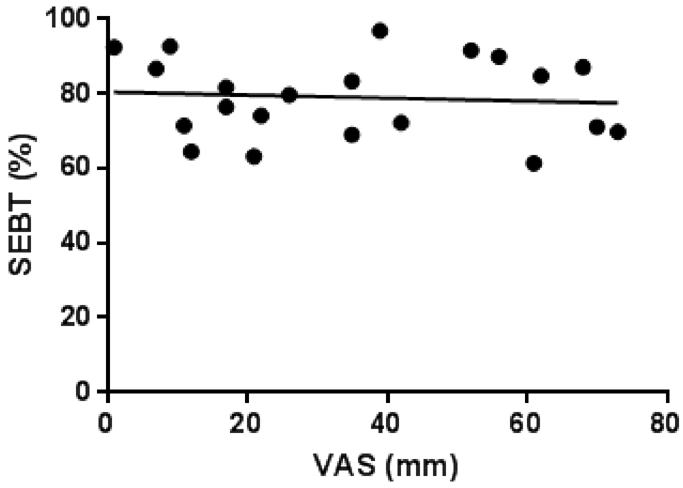
VAS (mm)


SEBT (%)
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60
80
VAS (mm)