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POSTURAL CONTROL AND BACK PAIN IN ADOLESCENT ATHLETES

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By

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Hereby, I declare that this thesis entitled “Postural control and back pain in adolescent athletes” or parts of the thesis have not yet been submitted for a doctoral degree to this or any other institution neither in identical nor in similar form. The work presented in this thesis is the original work of the author. I did not receive any help or support from commercial consultants. All parts or single sentences, which have been taken analogously or literally from other sources, are identified as citations. Additionally, significant contributions from co-authors to the articles of this cumulative dissertation are acknowledged in the authors’ contribution section.

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Abstract

Back pain is a problem in adolescent athletes affecting postural control which is an important requirement for physical and daily activities whether under static or dynamic conditions. One leg stance and star excursion balance postural control tests are effective in measuring static and dynamic postural control respectively. These tests have been used in individuals with back pain, athletes and non-athletes without first establishing their reliabilities. In addition to this, there is no published literature investigating dynamic posture in adolescent athletes with back pain using the star excursion balance test. Therefore, the aim of the thesis was to assess deficit in postural control in adolescent athletes with and without back pain using static (one leg stance test) and dynamic postural (SEBT) control tests.

Adolescent athletes with and without back pain participated in the study. Static and dynamic postural control tests were performed using one leg stance and SEBT respectively. The reproducibility of both tests was established. Afterwards, it was determined whether there was an association between static and dynamic posture using the measure of displacement of the centre pressure and reach distance respectively. Finally, it was investigated whether there was a difference in postural control in adolescent athletes with and without back pain using the one leg stance test and the SEBT.

Fair to excellent reliabilities was recorded for the static (one leg stance) and dynamic (star excursion balance) postural control tests in the subjects of interest. No association was found between variables of the static and dynamic tests for the adolescent athletes with and without back pain. Also, no statistically significant difference was obtained between adolescent athletics with and without back pain using the static and dynamic postural control test.

One leg stance test and SEBT can be used as measures of postural control in adolescent athletes with and without back pain. Although static and dynamic postural control might be related, adolescent athletes with and without back pain might be using different mechanisms in controlling their static and dynamic posture. Consequently, static and dynamic postural control in adolescent athletes with back pain was not different from those without back pain. These outcome measures might not be challenging enough to detect deficit in postural control in our study group of interest.

Zusammenfassung

Rückenschmerzen sind ein zunehmendes Problem bei Nachwuchsathleten und beeinflussen die statische und dynamische posturale Kontrolle, die eine wichtige Voraussetzung für sportliche als auch tägliche Aktivitäten darstellt. Der Stand auf einem Bein und der Star Excursion Balance Test (SEBT) sind effektive Test zur Beurteilung der statischen bzw. dynamischen posturalen Kontrolle. Beide Tests wurden bereits bei Populationen mit Rückenschmerzen, Sportlern und Nicht-Sportlern angewandt, ohne vorherige Reliabilitätsmessung. Des Weiteren wurde bisher die dynamische posturale Kontrolle mittels des SEBT bei Nachwuchsathleten mit Rückenschmerzen nicht untersucht. Daher ist das Ziel dieser Arbeit die posturale Kontrolle von Nachwuchsathleten mit Rückenschmerzen mit Hilfe eines statischen (Einbeinstand) und eines dynamischen (SEBT) Tests zu beurteilen.

Nachwuchsathleten mit und ohne Rückenschmerzen wurden mit Hilfe der beiden Tests untersucht. Die Reproduzierbarkeit beider Untersuchungen wurde durch vorhergehende Messungen sichergestellt. Anschließend wurde untersucht ob es einen Zusammenhang zwischen der statischen und dynamischen posturalen Kontrolle gibt, indem die Abweichungen des Druckmittelpunktes (center of pressure) auf einer Kraftmessplatte mit der erreichten Reichweite beim SEBT verglichen wurden. Abschließend, konnte untersucht werden ob es einen Unterschied in der posturalen Kontrolle zwischen Nachwuchsathleten mit und ohne Rückenschmerzen gibt.

Es konnten moderate bis hervorragende Reliabilitätswerte für den statischen (Einbeinstand) und dynamischen (SEBT) Test der posturalen Kontrolle in der untersuchten Zielgruppe festgestellt werden. Es konnte kein Zusammenhang zwischen den Parametern des statischen und des dynamischen Tests bei Nachwuchsathleten mit und ohne Rückenschmerzen gefunden werden. Weiterhin gab keinen signifikanten Unterschied zwischen den Parametern der statischen und dynamischen Haltungskontrolle in der beschriebenen Population.

Der Einbeinstand auf der Kraftmessplatte und der SEBT können zur Beurteilung der Haltungskontrolle bei Nachwuchsathleten mit und ohne Rückenschmerzen eingesetzt werden. Der fehlende Zusammenhang zwischen den Parametern der statischen und dynamischen Haltungskontrolle könnte darauf zurückzuführen sein, dass verschiedene neuromuskuläre Mechanismen für die Regulierung der statischen und dynamischen Haltungskontrolle bei den Athleten verantwortlich sein könnten. Demzufolge gab es keinen Unterschied weder in der statischen noch in der dynamischen posturalen Kontrolle zwischen Nachwuchsathleten mit und

ohne Rückenschmerzen. Anspruchsvollere Aufgaben sind nötig um die Defizite in der Haltungskontrolle von Nachwuchsathleten zu untersuchen.

1. Introduction

The most recent studies suggest back pain (BP) is an increasing problem in the adolescent athletic population (Müller, et al., 2016) (Calvo-Muñoz, Gómez-Conesa, & Sánchez-Meca, 2013) (Haus & Micheli, 2012). It is estimated that 2 - 4% of 11 – 13-year old athletes have BP, with the prevalence increasing up to 20% in 14 – 17-year olds (Müller, et al., 2016) (D'Hemecourt, Gerbino, & Micheli, 2000) (Schmidt, Zwingenberger, Walther, & al, 2014). BP causes injury, disruption of normal postural control (PC), alteration in trunk muscle activity and predispose adult athletes to instability (Ruhe, Fejer, & Walker, 2011) (Hrysomallis, 2011) (Moseley & Hodges., 2005) (Hodges, Moseley, Gabrielsson, & Gandevia, 2003) (Radebold, Cholewicki, Polzhofer, & Greene, 2001) (Brumagne, Cordo, Lysens, Verschueren, & Swinnen, 2000) (Hodges & Richardson, 1997). Therefore, assessment and periodic monitoring of PC in adolescent athletes is important to identify and rehabilitate the impaired posture and altered trunk muscle activity. In the clinical setting, PC assessments are used to evaluate initial deficits resulting from injury, risk of injury and improvement after the intervention for an injury. The assessment can be carried out statically or dynamically depending on the task performed. In the static condition a force platform or a valid, reliable clinical scale can be used (Gribble, Hertel, & Plisky, 2012). It involves standing as still as possible during the performance of one or two leg stance test with assessment of deviations in the location of the center of pressure (COP) measures derived from force plate data (Amiridis, Hatzitaki, & Arabatzi, 2003). In the general population, static postural assessment can differentiate individuals with back pain from those without back pain (Ruhe, Fejer, & Walker, 2011). The results are however conflicting in the athletic population (Mueller, et al., 2017), (Oyarzo, Villagrán, R.E., Carpintero, & Berral, 2014) (Harringe, Halvorsen, Renström, & Werner, 2008). In the only published literature on reliability of static PC in athletes, Harringe, Halvorsen, Renström, & Werner, 2008 used double leg stance test. However, superior balance is reported in athletes' due to repetitive training (Hrysomallis, 2011) and one-legged stance is often required to switch from two to one leg during performance of sports. Hence a more challenging task like one leg stance test would be appropriate as a static measure for adolescent athletes. Static measures do not however completely mimic movement tasks occurring during physical activities. Also, assessing PC by measuring deviations in COP as used in static tests require an expensive laboratory set-up and some advanced technological equipment which are not always readily available (Baratto, Morasso, Re, & Spada, 2002) (Ruhe, Fejer, & Walker, 2011). Hence the need for a dynamic postural control assessment (DPC) with an inexpensive, quick and convenient clinical tool. This form of assessment should involve some level of movement around a base of support that closely replicates the demands of physical activity in sports participation.

In assessing DPC, one test that has captured the attention of researchers and clinicians is the star excursion balance test (SEBT). The measure of DPC is determined by how far a participant can reach while maintaining a base of support. According to literature, it can provide objective measures to differentiate deficits and improvements in dynamic posture related to lower extremity injury and fatigue as well as predict injury to the lower extremity (Gribble, Hertel, & Plisky, 2012). The premise of this test is to determine if, while standing on an injured or affected limb to maintain stability, a deficit is produced in the reaching distances, indicating a deficiency in dynamic posture that might be associated with the pathologic condition in the stance limb (Gribble, Hertel, & Plisky, 2012). There is a delay in the feed-forward postural response leaving the spine unprotected when movement of the lower limb occurs (Hodges and Richardson 1998) in people with a history of back pain. Therefore, in a dynamic test such as the SEBT, one can assume that the vulnerability of the spine to further injuries would limit how far the limb would move. Back pain influences the trunk as well as lower limb movement (Müller, et al., 2016), therefore there is the possibility of detecting deficit in DPC using the measure of reach distance. Recent published articles on the use of the SEBT to measure dynamic posture among back pain subjects in the general population concluded that it is an effective and simple tool used to identify and measure reach deficits in this group of subjects (Tsigkanos, Gaskell, Smirniotou, & Tsigkanos, 2016) (Ganesh GS, 2015). Hence application of this measure to adolescent athletes may provide a more challenging task that could assist in the differentiation of adolescent athletes with and without back pain. At present, however, there is no published literature on the use of the SEBT to test dynamic posture in adolescent athletes with back pain.

Therefore, the aim of this thesis is to determine whether the SEBT and one leg stance test would be able to detect deficits in dynamic and static postural control respectively in adolescent athletes with and without back pain. This cumulative thesis comprises of three studies recently published in peer reviewed journals addressing the reproducibility of static and dynamic postural control test using the one leg stance test for the former and SEBT for the latter in adolescent athletes with and without back pain. The association between static and dynamic postural control in adolescent athletes with and without back pain and the determination of whether our measures of interest in adolescent athletes with back pain are different from those without pain.

2. Postural control and back pain in adolescent athletes

The postural control system is made up of sensory (vision, vestibular and proprioceptive systems), central nervous and musculoskeletal systems (Winter, Patla, & Frank, 1990). To regulate body posture, input from the sensory system is evaluated by the central nervous system and the plan of action to regulate the posture is carried out by the musculoskeletal system (Winter, Patla, & Frank, 1990). Under normal conditions, the primary mediators of postural awareness are the proprioceptive and visual subsystems (Lephart, 1998). To determine the positions and movement of body parts the proprioceptive system functions through the tactile and position senses (Guyton, 1986) (Vander, Sherman, & Luciano, 1990). The proprioceptors (Muscle spindles and Golgi tendon receptors) provide the central nervous system (CNS) with continuous feedback about the status of each muscle (Guyton, 1986) (Vander, Sherman, & Luciano, 1990). A muscle spindle which is a collection of several receptors consisting of afferent nerve fibre endings (Guyton, 1986) (Vander, Sherman, & Luciano, 1990) send information to the CNS about either the muscle length or the rate of change of the length (Vander et al. 1990). The CNS involvement in maintaining upright posture can be divided into sensory organization and muscle coordination (Nashner, 1982) (Shumway-Cook, 1986). It relies on one sense at a time for orientation information (Nashner, 1982).

The output of the postural control system is disorganized when a disorder occurs in any of the three sensory systems (Della Volpe et al. 2006). In the trunk, injury or damage to the proprioceptive tissues leads to increased body sway, delay action time and reduced activity (Sohn, Lee, & Song, 2013) (Boudreau S, 2011) (Moseley & Hodges., 2005) (Zedka M, 1999). Before a limb moves, the brain prepares the trunk by activating the deep and superficial trunk muscles (Hodges and Richardson 1997, 1999; Moseley et al. 2002a, b). Pain alters the strategy by which the brain prepares for movement (Hodges, Moseley, Gabrielsson, & Gandevia, 2003) as well as the amplitude of muscle activity during movement (Arendt-Nielsen L, 1996) (Madeleine P, 1999) (Zedka M, 1999). The deep trunk muscles fine-tune and reduce spinal control whilst the superficial ones cause the spine to stiffen through increased compression (Hodges PW C. A., 2001) (Hodges, et al., 2003a) (Richardson CA, 2002). The increased load of the spine stimulates nociceptors and predispose the spine to injury (Gardner-Morse & Stokes, 1998), (van Dieen, Selen, & Cholewicki, 2003).

Studies suggest that back pain is a problem in the general and athletic populations (Mueller, et al., 2017) (Delitto, 2002) (Smith & Sassmannshausen, 2002) (Haus & Micheli, 2012) (Schmidt, Zwingenberger, Walther, & al, 2014). It causes disruption of postural control (Moseley & Hodges., 2005) and alteration in trunk muscle activity (Radebold, Cholewicki, Polzhofer, & Greene, 2001), (Hodges & Richardson, 1997) (Hodges, et al., 2003a). In the adolescent athletic population, a point prevalence ranging between 2-20%, 1-year prevalence of 57%, and a lifetime prevalence of 66% have been reported (Hoy, Brooks, Blyth, & Buchbinder, 2010) (Schmidt, Zwingenberger, Walther, & al, 2014) (Müller, et al., 2016). Therefore, there is a need for periodic assessment and monitoring to identify and appropriately rehabilitate the altered or impaired trunk and postural control.

To evaluate initial deficits resulting from injury, risk of injury and improvement after the intervention for an injury, postural control assessments are used. This can be carried out statically or dynamically depending on the task performed. Static postural control is defined as the ability to maintain or keep the body as motionless as possible on a fixed, firm, unmoving base of support (Riemann, Caggiano, & Lephart, 1999), (Goldie, Bach, & Evans, 1989). It is also defined as the ability to maintain the base of support while minimizing movement of body segments and the center of mass (Winter, Patla, & Frank, 1990) (Gribble & Hertel, 2003). Static assessments are carried out by assessing deviations in the location of the centre of pressure (COP) through measures derived from force plate data or by using clinical scales (Gribble & Hertel, 2003) (Hodges, Moseley, Gabrielsson, & Gandevia, 2003), (Baratto, Morasso, Re, & Spada, 2002). Examples of static postural control test include one, double and tandem leg stance test (Munn, Sullivan, & Schneiders, 2010). The ability to transfer the vertical projection of the center of gravity around the supporting base (Goldie, Bach, & Evans, 1989) defines dynamic` postural control. Its assessment involves the completion of a functional task with purposeful movements without compromising an established base of support (Winter, Patla, & Frank, 1990), (Gribble & Hertel, 2003). Examples of dynamic postural control test reported in literature include star excursion balance test, time to stabilization, dynamic postural stability index (Meardon, Klusendorf, & Kernozek, 2016) and landing task (Munn, Sullivan, & Schneiders, 2010). By measuring the movement of the centre of mass, the centre of pressure, body segments and electromyographic activities, postural control is quantified, with the most measured parameter being center of pressure (Paillard & Noé, 2015). This is done with a force platform which is made up of a stable board under which load sensors are positioned (Paillard & Noé, 2015). Simple test can also be used although these tests are of little interest in adolescent athletes.

In the general population, static postural assessment like the double leg stance test can differentiate individuals with and without back pain (Ruhe, Fejer, & Walker, 2011). The results are however conflicting in the athletic population (Mueller, et al., 2017) (Oyarzo, Villagrán, R.E., Carpintero, & Berral, 2014) (Harringe, Halvorsen, Renström, & Werner, 2008). Authors recommend a more challenging task, perturbation tests and neuromuscular approach using electromyographic analysis to assess the postural control system in athletes because of the need to challenge it to obtain useful information (Harringe, Halvorsen, Renström, & Werner, 2008). However, assessing PC using these methods require an expensive laboratory set-up, advanced technological equipment which are not always readily available (Ruhe, Fejer, & Walker, 2011) (Baratto, Morasso, Re, & Spada, 2002) coupled with challenges in transferring the results to everyday athletic training.

The one-legged stance is often required to switch from two legs to one during the performance of sports, hence it would be appropriate as a static measure for adolescent athletes. The reliability of sway parameters on a force platform using the one leg stance test is moderate to excellent in developing children and excellent in healthy young adults (De Kegel, et al., 2011), (Ruhe, Fejer, & Walker, 2011), (Goldie, Bach, & Evans, 1989). The SEBT could also be considered as a dynamic test for this group of individuals. It is an effective tool to identify and measure reach deficits in subjects with back pain in the general population (Ganesh GS, 2015) . It is a simple, inexpensive, rapid, reliable and valid tool for assessing dynamic PC (Hertel, Miller, & Denegar, 2000). It is effective in measuring multi-planar excursion with strong inter-rater and intra-rater reliability measurements (Bastien, et al., 2014) (Hertel, Miller, & Denegar, 2000), responsiveness and criterion validity (Gribble & Hertel, 2003). It is performed by establishing a stable base of support on the stance limb in the middle of a testing grid whilst performing a maximum excursion of the non-stance limb along prescribed directions. These are all done without shifting weight on the stance limb or coming to rest on the reaching limb (Gribble & Hertel, 2012) (Gribble & Hertel, 2003). The performance of the SEBT relies largely on the ability to maintain a static, stable and firm balance on the stance limb during both static and dynamic components of the test. According to (Ganesh GS, 2015), it is an effective tool to identify and measure reach deficits in subjects with low back pain. In back pain subjects, movement of the upper and lower limbs are associated with a delay in the onset of activation of the trunk muscles (Hodges & Richardson, 1999) (Allison, Morris, & Lay, 2008)) causing a delay in the stabilization of the spine. Trunk strength influences performance in athletic competition which is important in preventing injuries related to sports in adolescent athletes (Kibler, Press, & Sciascia, 2006) (Borghuis, Hof, & Lemmink, 2008) . Published literature confirms increased COP deviation coupled with reduced performance on the SEBT (Tsigkanos, Gaskell, Smirniotou, & Tsigkanos, 2016) in adults with back pain. This association, if confirmed in adolescent athletes will be important as dynamic postural control measurements specifically the SEBT can be used in adolescent athletes with back pain.

The static and dynamic postural control assessment tools discussed above have been used to assess postural control in individuals with back pain, athletes (Appiah-Dwomoh, Müller, Hadzic, & Mayer, 2016) and non-athletes alike (Ganesh GS, 2015) without first establishing the reliability of the test in these groups. Also, measurement took place in healthy subjects, requiring lots of caution in transferring the results unto injured individuals, athletes and different age groups. Therefore, the aim of the thesis was to determine deficit in postural control in adolescent athletes with and without back pain using static (one leg stance test) and dynamic (SEBT) postural control tests. Three objectives were answered to arrive at this aim. The first was to determine the test-retest reproducibility of static and dynamic postural control measurements in adolescent athletes with and without BP using the one leg stance for the former and the SEBT for the latter.

The second objective was to determine whether reproducibility of these tests was different between the athletes of interest and whether there was an association between the displacement of the COP on the stance limbs on the static test and the reach distance of the non-stance limb on the dynamic test with consideration to the back-pain status. The final objective was to determine if static and dynamic posture, measured by the one leg stance test mean displacement and the SEBT reach distance, in adolescent with back pain was different from those without pain.

The three studies included in this thesis have been published in peer-reviewed journals. Table 1 gives details about the journals, study-design, participants and measurements performed in each of the study.

Table 1: Characteristics of the studies included in the present thesis

Study	Journal	Design	Participant	Measures	Chapter
1	Rehabilitation research and practice	Test-Retest	BP (n = 14), NBP (n = 17)	One leg stance test	3.1
		1-week interval	Mean age: 14 ± 2 years	Star excursion balance test	
2	German Journal of Exercise and Sport Research	Cross sectional	128 adolescent athletes.	One leg stance test	3.2
			Mean age: 14 ± 1 years	Star excursion balance test	
3	Sports	Cross sectional	BP (n = 53), NBP (n = 53)	Star excursion balance test	3.3
			Mean age: 14.5 ± 1.3 years		

BP = back pain, NBP = no back pain

3. Studies

3.1 Study

Reproducibility of Static and Dynamic Postural Control Measurement in Adolescent Athletes with Back Pain

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Reference

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3.1.1 Abstract

Static (one leg stance) and dynamic (star excursion balance) postural control tests were performed by 14 adolescent athletes with and 17 without back pain to determine reproducibility. The total displacement, mediolateral and anterior-posterior displacements of the centre of pressure in mm for the static, and the normalized and composite reach distances for the dynamic tests were analysed. Intraclass correlation coefficients, 95% confidence intervals, and a Bland-Altman analysis were calculated for reproducibility. Intraclass correlation coefficients for subjects with (0.54 to 0.65), (0.61 to 0.69) and without (0.45 to 0.49), (0.52 to 0.60) back pain were obtained on the static test for right and left legs, respectively. Likewise, (0.79 to 0.88), (0.75 to 0.93) for subjects with and (0.61 to 0.82), (0.60 to 0.85) for those without back pain were obtained on the dynamic test for the right and left legs, respectively. Systematic bias was not observed between test and retest of subjects on both static and dynamic tests. The one leg stance and star excursion balance tests have fair to excellent reliabilities on measures of postural control in adolescent athletes with and without back pain. They can be used as measures of postural control in adolescent athletes with and without back pain.

3.1.2 Background

Studies suggest that back pain (BP) is a problem in the general and athletic populations (Müller, et al., 2016), (George & Delitto, 2002), (Smith & Sassmannshausen, 2002), (Haus & Micheli, 2012), (Schmidt, Zwingenberger, Walther, & al, 2014). It causes disruption of postural control (PC) (Moseley & Hodges., 2005) and alteration in trunk muscle activity (Radebold, Cholewicki, Polzhofer, & Greene, 2001) (Hodges & Richardson, 1997), (Hodges, et al., 2003a). Hence, there is a need for periodic assessment and monitoring to identify and appropriately rehabilitate the altered or impaired trunk and postural control. This can be done statically by assessing deviations in the location of the centre of pressure (COP) through measures derived from force plate data using the one leg stance test (Hodges, et al., 2003a), (Baratto, Morasso, Re, & Spada, 2002). Dynamically, the assessment can be made by completing a movement task whilst maintaining a stable base of support using the star excursion balance test (SEBT) (Kinzey & Armstrong, 1998)

In typically developing children, the reliability of sway parameters on a force platform using the one leg stance test are generally moderate to excellent (De Kegel, et al., 2011). Healthy young adults also show excellent intra- and intersession reliability (Ruhe, Fejer, & Walker, 2011), (Goldie, Evans, & Bach, 1992). In the only published literature on the reliability of static postural control in athletes, (Harringe, Halvorsen, Renström, & Werner, 2008) used a double-leg stance test. However, superior balance is reported in athletes due to repetitive training (Bressel, Yonker, Kras, & Heath, 2007), and a one leg stance is often required to switch from two legs to one during the performance of sports. Hence, a more challenging task like the one leg stance test would be appropriate as a static measure for this group of individuals. In the dynamic test, SEBT, (Kinzey & Armstrong, 1998) were the first to examine the reliability, conducting their study in a healthy general population of adults. They reported moderate to high reliability with intraclass correlation coefficients (ICC) ranging from 0.67 in the right anterior direction to 0.87 in the left anterior and left posterior directions (Kinzey & Armstrong, 1998). In adult recreational athletes, (Munroo & Herrington, 2010) also reported excellent reliability (ICC; 0.84 to 0.92) for all directions on the test. ICC ranging from 0.84 to 0.87 and 0.51 to 0.93 for the 3 reach directions of the SEBT has also been reported for high school basketball players (Plisky, Rauh, Kaminski, & Underwood, 2006) and primary school children (Calatayud, Borreani, Colado, Martin, & Flandez, 2014), respectively. The SEBT has been used to assess postural control in individuals with back pain, athletes (Appiah-Dwomoh, Müller, Hadzic, & Mayer, 2016) and nonathletes alike (Ganesh GS, 2015) without first establishing the reliability of the test in these groups. Also, in published literature, measurement of the reliabilities of both the one-leg stance test and the SEBT took place in healthy subjects; therefore, it cannot be assumed that this will remain the same in injured individuals and athletes and different age groups. In addition to this, athletes have superior balance abilities due to training (Bressel, Yonker, Kras, & Heath, 2007), and this needs to be taken into consideration. Furthermore, BP damages the sensory tissues and pain inhibition in the lumbar spine and trunk is believed to affect the PC mechanism (Radebold, Cholewicki, Polzhofer, & Greene, 2001), (Brumagne, Cordo, Lysens, Verschueren, & Swinnen, 2000). This might lead to the adoption of alternative PC strategies to cope with the new demands introduced by pain (Baratto, Morasso, Re, & Spada, 2002). Also, individuals with BP show changes in the position of their centre of pressure compared to pain-free subjects (Byl & Sinnott, 1991), (Mientjes & Frank, 1999), and differences in PC exist between injured and non - injured individuals (Harringe, Halvorsen, Renström, & Werner, 2008). Therefore, the aim of the study was to determine the test-retest reproducibility of static and dynamic PC measurements in adolescent athletes with and without BP using the one-legged stance for the former and the SEBT for the latter. A second aim was to determine whether reproducibility of these tests was different between adolescent athletes with and without BP.

3.1.3 Methods

3.1.3.1 Participants

A total of 35 adolescent athletes were recruited for the study. 4 subjects (1 BP and 3 NBP) were excluded due to the report of chest pains and knee and shin injuries prior to retest as well as data acquisition challenges. Therefore, 14 BP athletes (14.6 ± 1.4 years, 66.0 ± 8.3 kg, 173.8 ± 5.3 cm, 4.7 ±2.5 training years, 8.9 ± 3.9 training sessions/week, 96.1 ± 18.0 training minutes/session) and 17 NBP athletes (13.8 ±1.5 years, 58.8 ± 13.2 kg, 170.3 ± 12.2 cm, 3.9 ± 2.5 training years, 7.1 ± 3.3 training sessions/week, 98.8 ± 23.2 training minutes/session) were included in the final data analysis. The athletes were from 7 different sport disciplines: athletics (n = 6), rowing (n =7), canoeing (n = 4), swimming (n = 1), football (n = 8), handball (n = 3), and volleyball (n = 2). A pain questionnaire consisting of a numeric rating scale of 1 (no pain) to 5 (severest pain) in the form of smiley faces was used to determine participants with BP (Ellert, Neuhauser, & Roth-Isigkeit, 2007). BP was not confined to a specific region of the back and was defined as pain rating from 2 to 5 on the pain questionnaire. The mean BP score at initial testing was 3 ± 0.8 and 2.8 ± 1.0 at retest. Subjects with lower and upper limb injuries, head injuries, vision problems, and any other complaints that could have affected the balance measurement were excluded. The institution's ethics committee gave ethical approval and participants and their parents or guardians gave written informed consent before data collection.

3.1.3.2 Procedure

Age, gender, weight, height, number of training years, training days per week, training minutes per session, and type of sports engaged in by the subjects were recorded. All subjects performed the one leg stance test first, followed by the SEBT. Participants performed two test sessions 7 days apart. The first test was conducted by instructing participants to stand on one leg on a force plate (Advanced Mechanical Technology Inc. (AMTI, OR6-6, Massachusetts, USA)) and slightly flex the free leg at the hip and knee. The standing leg was slightly flexed at the knee with eyes open. Maintaining their hands on their waist, they focused on an imaginary object straight ahead. The testing protocol included 3 repetitions of 15 seconds for each leg. The starting limb was chosen randomly. After the examiner instructed and demonstrated the testing situation, participants were given one practice trial before the main test. Practice and test trials were considered invalid if the participant removed their hands from the waist, dropped down, or touched the force plate with the non - standing limb, or moved the standing limb. Displacements of the COP in the mediolateral and anterior-posterior directions were recorded with Netforce (AMTI). The sampling frequency was 1000Hz and data was acquired for 15s. Time series signals were filtered using a Butterworth filter with a cut-off frequency of 12 Hz after which the following COP parameters were calculated for 10-second time interval: mean total COP displacement (COP_tot), mean displacement of the COP in anterior-posterior (COP_ap), and mediolateral (COP_ml) directions.

The SEBT was carried out after the one leg stance test was completed. The shortened version includes the anterior, posteromedial, and posterolateral directions. 3 tape measures with a centimetre scale were affixed onto the laboratory floor. The first reach direction was aligned anterior to the apex; the other two were oriented 135 degrees to the first in the posteromedial and posterolateral directions (Coughlan, Fullam, Delahunt, Gissane, & Caulfield, 2012). Maintaining a single-leg stance, participants were instructed to reach out as far as possible with the non - stance limb along the marked tape, point to the most distal portion with their big toe, and return the limb back to the starting position (Plisky, Rauh, Kaminski, & Underwood, 2006). Subjects practiced each direction 4 times before the actual testing to minimize learning effects

(Hertel, Miller, & Denegar, 2000), (Robinson & Gribble, 2008). This was followed by the recording of 3 successful trials in each direction for both legs, always with a 10-s rest between each test (Robinson & Gribble, 2008). The order of the starting limb was randomized, and the chronology of the directions was defined ((1) Anterior, (2) Posteromedial, and (3) Posterolateral). The subject's starting foot was placed on the convergence of the reach directional lines of the SEBT (Coughlan, Fullam, Delahunt, Gissane, & Caulfield, 2012). In this way, the lateral malleolus was positioned at the intersection point of the 3 directions, with the foot's longitudinal axis oriented towards the anterior direction. The starting position was a bilateral limb stance. Subjects performed the test with socks on and kept their hands on their hips throughout the testing period. The limb length of the subjects was then taken with a measuring tape. This was defined as the distance from the anterosuperior iliac spine to the medial malleolus (Terry, et al., 2005). Maximum reach distance was visually read by the same examiner for all subjects. A trial was considered invalid if the reaching foot did not return to the starting position, if it touched down whilst reaching out, if the support limb shifted, if the heel of the support foot did not stay in contact with the ground or if the hands were removed from the hips.

3.1.3.3 Outcome Measures and Statistical Analysis

Outcome measures of interest included the mean of the total COP displacement (COP_tot) and the mean displacement of the COP in the anterior-posterior (COP_ap) and mediolateral directions (COP_ml), all in millimetres. Mean normalized reach distance in anterior, posteriomedial, and posterolateral directions was expressed as the percentage of limb length and composite reach distance score (CRDS) for the SEBT ((Holden, Boreham, Doherty, Wang, & Delahunt, 2014). The composite reach distance was calculated as the sum of the 3 normalized SEBT scores (Holden, Boreham, Doherty, Wang, & Delahunt, 2014).

The relevant (nondigital) data for analysis was handwritten into a case report form, after which the computation was performed. Mean and standard deviations followed by paired t-tests and a Wilcoxon signed rank test for normally and nonnormally distributed data, respectively, were carried out. The intraclass correlation coefficient ICC (2, 1) for both limbs for each outcome measure was then calculated. Criteria ranges for ICC reliability were as follows: < 0.40, poor; 0.40 to 0.75, fair to good and > 0.75, excellent reliability (Fleiss, 1999). Also, a Bland-Altman analysis (Bland & Altman, 1986) (was used as an indicator of absolute reliability. The difference of the test-retest scores was plotted against their average as well as the limits of agreement. In addition to these, a post hoc power analysis was carried out using G Power 3.1.9.2 (Faul, Erdfelder, Buchner, & Lang, 2009) to determine whether the research was adequately powered. The effect size (f) was calculated using the formula (mean of test —mean of retest)/pooled standard deviation of both tests. Bonferroni corrections were carried out to correct for any type-one error that might occur due to multiple analyses on the same dependent variable; hence the level of significance was set at $\alpha = (0.05/4) = 0.0125$. Statistical analysis was carried out using SPSS version 24 (SPSS Inc., Chicago, IL, USA).

3.1.4 Results

The scores from the two testing sessions did not reveal any significant difference ($P > 0.0125$) in the outcome measures of the one leg stance test for subjects with back pain as shown in

Table 2 .

Table 2: Mean ± SD (mm), 95% CI and effect size for the outcome measures of the one leg stance test for subjects with back pain during test and re-test sessions.

		Test		Retest		
		Mean ± SD	**95% CI**	**Mean ± SD**	**95% CI**	**Eff. S.**
	Right					
BP	COP_ap	295.8 ± 94.8	241.0 – 350.5	253.0 ± 64.5	215.8 – 290.3	0.527
	COP_ml	263.6 ± 58.8	229.6 – 297.5	274.2 ± 75.6	230.6 – 317.9	-0.157
	COP_total	434.6 ± 113.9	368.8 – 500.4	413.9 ± 104.1	353.8 – 474.0	0.190
	Left					
	COP_ap	276.3 ± 100.2	218.4 – 334.2	268.7 ± 79.3	222.9 – 314.5	0.084
	COP_ml	253.9 ± 51.4	224.2 – 283.6	266.1 ± 75.1	222.7 – 309.5	-0.190
	COP_total	416.4 ± 113.5	350.9 - 481.9	424.7 ± 114.8	358.4 - 491.0	-0.059

Eff.S. =Effect Size

The scores from the two testing sessions did not reveal any significant difference ($P > 0.0125$) in the outcome measures of the one leg stance test for subjects without back pain as shown in Table 3.

Table 3: Mean ± SD (mm), 95% CI and effect size for the outcome measures of the one leg stance test for subjects without back pain during test and re-test sessions.

		Test		Retest		
		Mean ± SD	**95% CI**	**Mean ± SD**	**95%CI**	**Eff. S.**
	Right					
NBP	COP_ap	288.1 ± 72.1	251.0 – 325.1	315.1 ± 123.8	251.5 – 378.7	-0.238
	COP_ml	292.5 ± 82.4	250.1 – 334.8	307.5 ± 130.1	240.6 – 374.4	-0.121
	COP_total	462.5 ± 122.0	399.8 – 525.3	498.0 ± 211.3	389.3 – 606.7	-0.184
	Left					
	COP_ap	288.8 ± 69.9	252.9 – 324.8	292.7 ± 80.5	251.3 – 334.1	-0.043
	COP_ml	296.6 ± 61.9	264.8 – 328.5	274.1 ± 67.9	239.1 – 309.0	0.287
	COP_total	459.0 ± 101.1	407.0 – 511.0	446.1 ± 112.3	388.3 – 503.8	0.1

Eff.S. =Effect Size

BP and NBP subjects recorded the ICCs of 0.54 to 0.69 and 0.45 to 0.60, respectively, for all the outcome measures of the one-legged stance test (see Table 4).

Table 4: Intra-class correlation coefficients with 95% confidence interval for the one-legged stance test calculated for test-retest reliability for BP and NBP

		Right		Left	
		ICC	**95% CI**	**ICC**	**95%CI**
BP	COP_ap	0.69	0.3 – 0.9	0.65	0.2 – 0.9
	COP_ml	0.61	0.1 – 0.9	0.54	0.0 – 0.8
	COP_tot	0.63	0.2 – 0.9	0.64	0.2 – 0.9
NBP	COP_ap	0.49	0.0 – 0.8	0.52	0.1 – 0.8
	COP_ml	0.47	0.0 – 0.8	0.60	0.2 – 0.8
	COP_tot	0.45	-0.2 – 0.8	0.57	0.1 – 0.8

There was no significant difference ($p > 0.0125$) in any of the directions for the SEBT between test-retest scores for both limbs of the BP subjects, as reported in Table 5.

Table 5: Mean ± SD (% of limb length), 95% CI and effect size for the different directions on the SEBT during test and retest for back pain subjects.

	Reach distance	Test		Retest		
		Mean ± SD	**95% CI**	**Mean ± SD**	**95%CI**	**Eff.S.**
	Right					
BP	Anterior	89.3 ± 8.2	84.5 - 94.0	88.4 ± 6.2	84.8 – 91.9	0.097
	Posteromedial	83.4 ± 10.0	77.7 – 89.2	84.5 ± 8.4	79.7 – 89.3	-0.095
	Posterolateral	79.6 ± 9.4	74.2 – 85.0	81.9 ± 9.5	76.4 – 87.4	-0.199
	CRDS	84.1 ± 8.8	79.0 – 89.2	84.9 ± 7.6	80.5 – 89.3	-0.078
	Left					
	Anterior	89.3 ± 7.4	85.0 – 93.6	89.0 ± 5.8	85.6 – 92.3	0.354
	Posteromedial	85.1 ± 10.1	79.2 – 90.9	84.7 ± 9.9	79.0 – 90.4	0.033
	Posterolateral	79.4 ± 10.0	73.6 – 85.2	81.8 ± 10.4	75.8 – 87.8	-0.193
	CRDS	84.6 ± 8.8	79.5 – 89.6	85.2 ± 8.4	80.3 – 90.0	-0.057

There was no significant difference (p > 0.0125) in any of the directions for the SEBT between test-retest scores for both limbs of the NBP subjects, as reported in Table 6.

Table 6: Mean ± SD (% of limb length) 95% CI and effect size for the different directions on the SEBT during test and retest for subjects without back pain.

	Reach distance	Test		Retest		
		Mean ± SD	**95% CI**	**Mean ± SD**	**95%CI**	**Effect size**
	Right					
	Anterior	88.4 ± 8.2	84.2 – 92.6	87.8 ± 7.8	83.8 – 91.8	0.061
	Posteromedial	79.9 ± 9.2	75.2 – 84.6	81.0 ± 9.3	76.3 – 85.8	-0.097
	Posterolateral	79.8 ± 9.3	75.0 – 84.6	78.9 ± 9.8	73.9 – 84.0	0.078
NBP	CRDS	82.7 ± 7.9	78.6 – 86.6	82.6 ± 8.0	78.5 – 86.7	0.010
	Left					
	Anterior	88.9 ± 8.6	84.5 – 93.4	89.2 ± 7.5	85.4 – 93.1	-0.030
	Posteromedial	80.6 ± 10.4	75.3 – 86.0	81.2 ± 10.0	76.1 – 86.4	-0.048
	Posterolateral	78.1 ± 12.6	71.6 – 84.6	78.6 ± 10.0	73.5 – 83.7	-0.035
	CRDS	82.6 ± 9.7	77.6 – 87.6	83.0 ± 8.3	78.7 – 87.3	-0.035

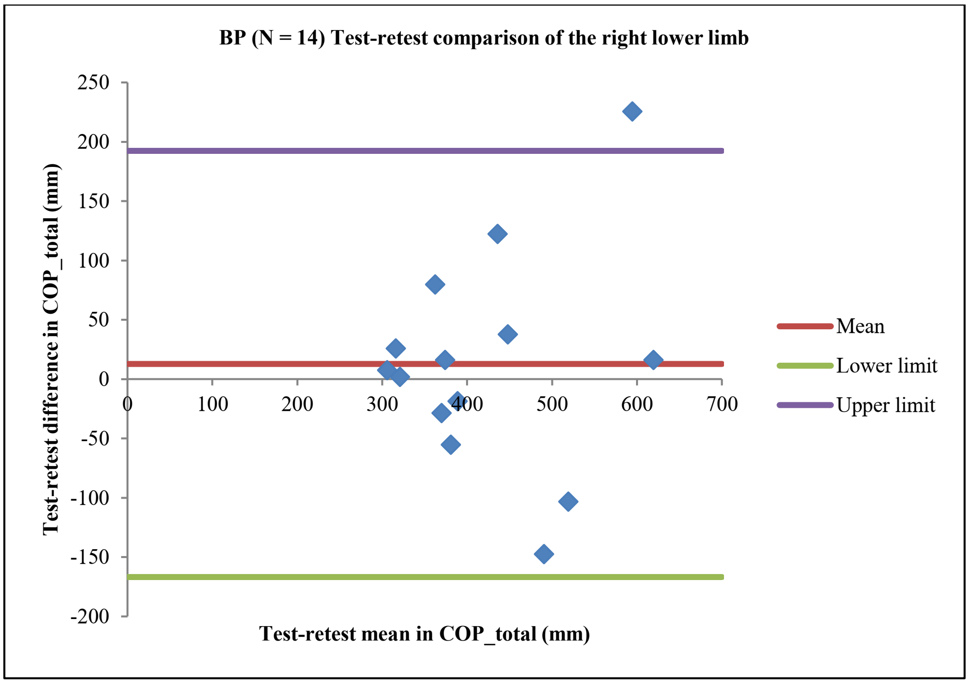
ICCs of (0.75 to 0.93) and (0.60 to 0.85) were recorded for subjects with and without back pain, respectively, for the outcome measures of the SEBT as shown in Table 7 below.

Table 7: Intra-class correlation coefficients with 95% confidence interval for test-retest reliability of subjects with and without back pain on the SEBT.

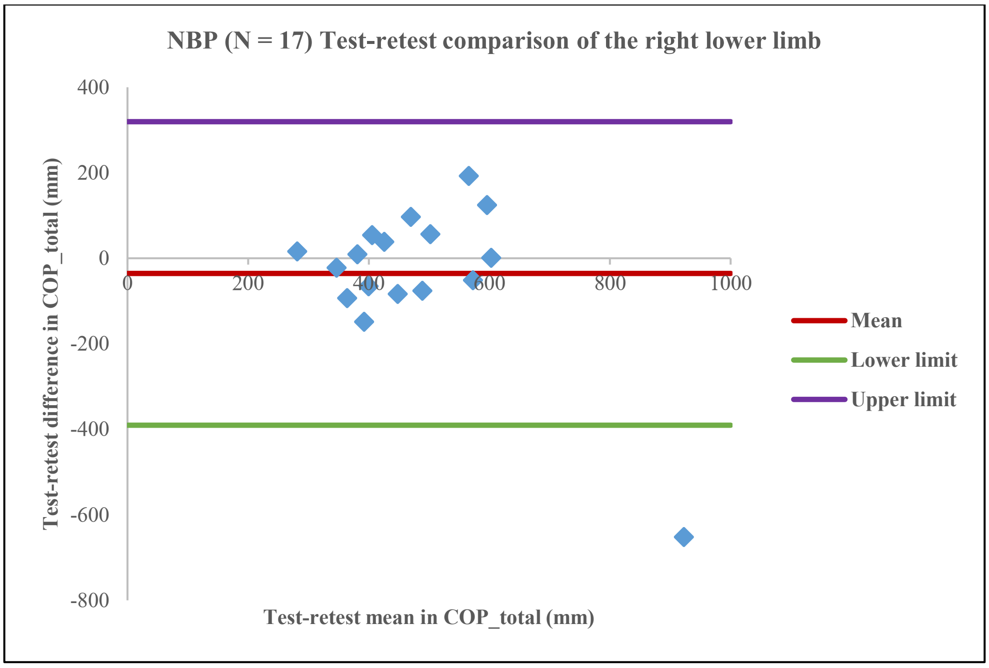
Test-retest reliability					
		Right		Left	
	Reach distance	**ICC**	**95% CI**	**ICC**	**95% CI**
BP	Anterior	0.79	0.4 – 0.9	0.75	0.4 – 0.9
	Posteromedial	0.88	0.7 – 1.0	0.89	0.7 – 1.0
	Posterolateral	0.85	0.6 – 0.9	0.93	0.8 – 1.0
	CRDS	0.86	0.6 – 1.0	0.91	0.7 – 1.0
NBP	Anterior	0.82	0.6 – 0.9	0.85	0.6 – 0.9
	Posteromedial	0.79	0.5 – 0.9	0.60	0.2 – 0.8
	Posterolateral	0.61	0.2 – 0.8	0.65	0.3 – 0.9
	CRDS	0.74	0.4 – 0.9	0.69	0.3 – 0.9

Test-retest values did not reveal any significant difference (P > 0.0125) between the right and left lower limbs of athletes with and without back pain for all outcome measures of both the one-legged stance test and the SEBT when the 95% CIs are observed. Only results of COP_tot and CRDS of the right lower limb is reported for the Bland-Altman, as there was no significant difference or systematic bias between test and retest for subjects with and without back pain as shown in (b) (a,b,c,d) below.

(a)

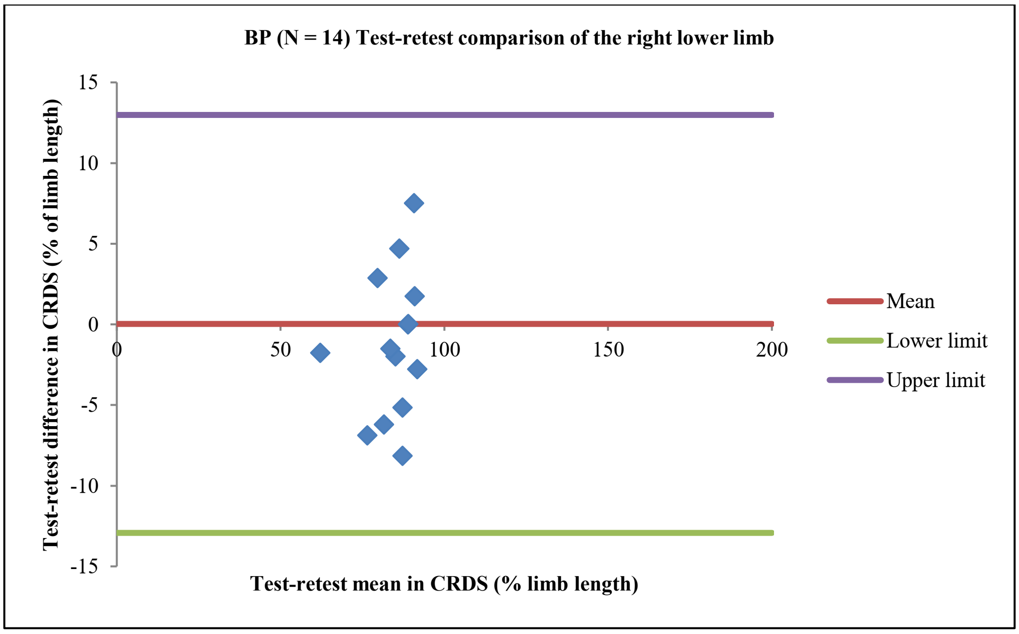


(b)



NBP (N = 17) Test-retest comparison of the right lower limb
400
200
0
-200
-400
-600
-800
0
200
400
600
800
1000
Test-retest difference in COP_total (mm)
Test-retest mean in COP_total (mm)
Mean
Lower limit
Upper limit

(c)



BP (N = 14) Test-retest comparison of the right lower limb
15
10
5
0
-5
-10
-15
0
50
100
150
200
Test-retest difference in CRDS (% of limb length)
Test-retest mean in CRDS (% limb length)
Mean
Lower limit
Upper limit

(d)

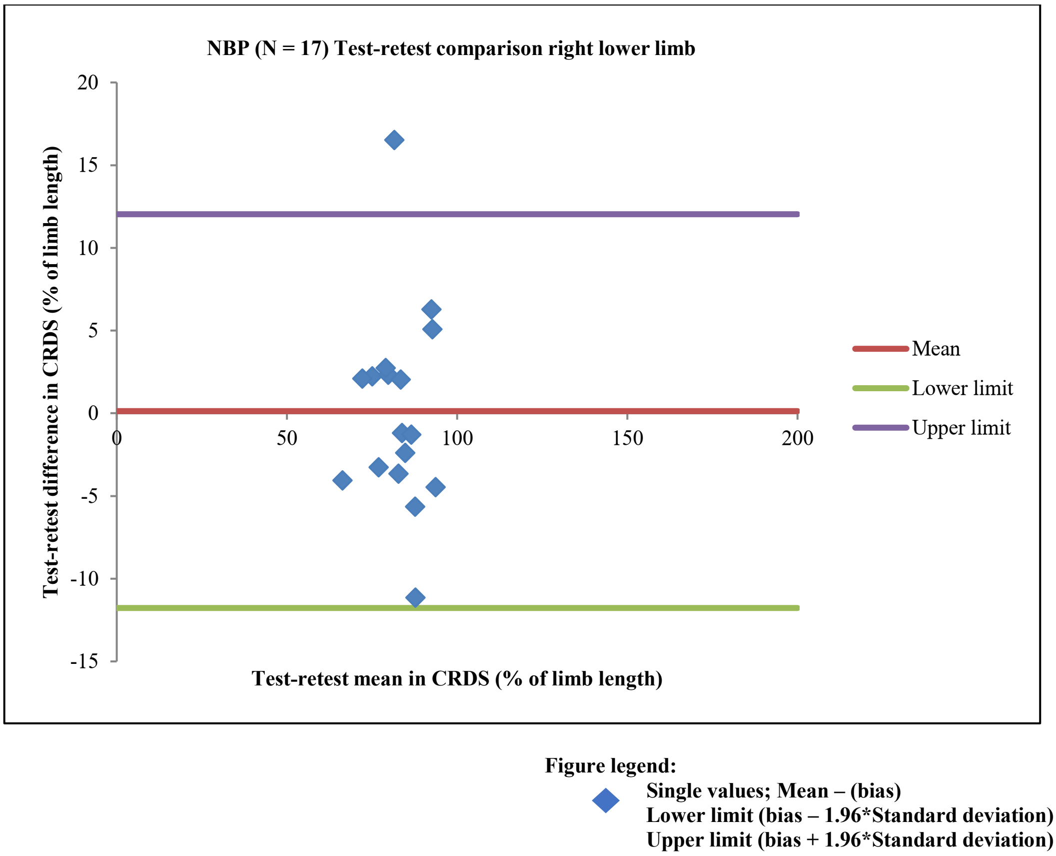


Figure 1: Bland-Altman plot for the right lower limb of adolescent athletes with and without back pain on the one-legged stance test and the star excursion balance test

3.1.5 Discussion

The study aimed to determine the test-retest reproducibility of static and dynamic PC in adolescent athletes with and without back pain using the one leg stance test and the SEBT. It also aimed to determine whether there was a difference in the reliabilities of the dynamic and static PC tests. The present results show that, in adolescent athletes with and without back pain, the reliability of the one leg stance test is fair to good on all outcome measures. Also, the reliability of the SEBT is good to excellent for subjects with and without back pain. In addition to these, there was no statistically significant difference in the reliabilities of either the static or dynamic test for adolescent athletes with and without back pain.

The fair-to-good reliability of the outcome measures of the one leg stance test for adolescents both with and without back pain adds to the various COP parameters reported to be reliable in literature (Goldie, Evans, & Bach, 1992), (Harringe, Halvorsen, Renström, & Werner, 2008), (De Kegel, et al., 2011), (Ruhe, Fejer, & Walker, 2011), (Muehlbauer, Roth, Mueller, & Granacher, 2011). The results, however, cannot be directly compared without caution to those reported in the literature due to differences in the study population, testing duration, COP parameters used, type of stance employed, and testing surface used. The most reliable test-retest reliability was detected in female gymnasts whilst standing on a foam surface during 60s-test durations performing bipedal task (Harringe, Halvorsen, Renström, & Werner, 2008). This observation differs from the fair-to-good reliability observed in the current study using a test duration of 15s, a firm surface, and the one leg stance test. This could be because postural control deficits become more evident during the execution of challenging tasks, as well as the need to challenge the postural control system to obtain useful information from the COP measurements (Harringe, Halvorsen, Renström, & Werner, 2008) due of the study population. Thus, the one leg stance test might have provided the needed challenge.

The total mean displacement of the COP in the present study was almost 3 times lower for both test and retest in back pain subjects compared to that obtained by (Muehlbauer, Roth, Mueller, & Granacher, 2011) (test: 1,223.2 mm and 1,133.1 mm and retest: 1,099.3 mm and 1,013.3 mm for men and women, respectively). This difference could be due to the younger study population in the present study. Greater postural sway is reported in older compared to younger adults when the base of support is narrowed (Amiridis, Hatzitaki, & Arabatzi, 2003), and even more so with athletes who generally have superior balance ability due to participation in sports (Hrysomallis, 2011). Also, the test-retest values recorded for back pain athletes were lower compared to those without back pain (see Table 1) in the present study. This, however, did not reach a significant level, as observed in the 95% CIs. (Harringe, Halvorsen, Renström, & Werner, 2008) reported a nonsignificant difference between their back pain and healthy subjects, supporting the current results. This could be due to the adoption of alternative postural control strategies by the athletes with back pain to cope with the new demands introduced by the pain (Radebold, Cholewicki, Polzhofer, & Greene, 2001).

The reliability of the SEBT in adolescent athletes with back pain was excellent (ICC: 0.75 to 0.93), whilst that for those without pain was good to excellent (ICC: 0.60 to

0.85). These results are in the range of ICC values previously reported for healthy adults (0.67 to 0.87 (Kinzey & Armstrong, 1998), 0.78 to 0.96 (Hertel, Miller, & Denegar, 2000), basketball athletes (0.84 to 0.87) (Calatayud, Borreani, Colado, Martin, & Flandez, 2014) and primary school children (0.51 to 0.93) (Brumagne, Cordo, Lysens, Verschueren, & Swinnen, 2000). The current investigation supports the reliability of the SEBT in adolescent athletes with and without back pain. The body relies on rapid, continuous feedback from three integrated but independent sensory sources to execute smooth and coordinated neuromuscular actions (Nashner, 1982). As back pain influences the trunk as well as lower limb movement (Müller, et al., 2016), there is the possibility of detecting deficits in dynamic postural control using the measure of reach distance. This is because the feedback from the reach leg to the sensory sources of the postural control might be interrupted during performance of the SEBT (Coughlan, Fullam, Delahunt, Gissane, & Caulfield, 2012). Therefore, application of this tool in adolescent athletes may prove a more challenging task that could help further assess and monitor deficits resulting from back pain. A Bland-Altman plot for COP_tot showed little suggestion of a bias, as the mean differences between the test and retest of all the outcome measures for the one leg stance test for athletes with and without back pain were close to zero. (Muehlbauer, Roth, Mueller, & Granacher, 2011) also reported similar results for COP_tot in their investigation involving healthy adults on the one leg stance test, supporting the current result. The good-to-excellent reliability reported for the SEBT was confirmed in the Bland-Altman analysis. Based on the plot, the conclusion can be drawn that there is no statistically significant difference between the test-retest scores of the outcome measures of the SEBT reported in this investigation. Bland-Altman analyses have not been reported in published investigations of reproducibility involving the SEBT; hence a direct comparison cannot be made with the published literature.

The confidence intervals of the reliabilities of the static and dynamic tests overlapped for subjects both with and without back pain. Also, within each test, there was an overlap of the confidence intervals between subjects with and without back pain. Therefore, one can conclude that there is no statistically significant difference between the static and dynamic tests, as well as between subjects with and without back pain, in our study population. A power analysis showed that, based on the lowest (f = 0.010) and highest (f = 0.527) effect sizes observed in the present study, approximately 95053 and 37 subjects would be needed respectively in both BP and NBP groups to obtain a statistical power at a 0.80 level (Cohen, 1988).

3.1.5.1 Limitations of the Study

The pain questionnaire may be considered a limitation of this study, as it only assessed pain within 7 days prior to participation in the study. Hence, the possibility of varying phases and locations of BP and its effect on the current results cannot be ruled out. In addition to this, a mean pain score of 3.0 ± 0.8 for our cohort might be too low to show previously reported impact of back pain on postural control. Another limitation might be the varying sports disciplines considered together in the study, as the SEBT might be sensitive to sport-related adaptations (Thorpe & Ebersole, 2008), and the distinct skill requirements and environmental demands of different sports likely pose different challenges to the sensorimotor systems (Portney & Watkins, 2008). In addition to these, further investigation is required to ascertain the effect of gender on the current results, as there is a lack of agreement on the effect of gender on the SEBT, with the literature reporting both no effects (Bressel, Yonker, Kras, & Heath, 2007), (Fleiss, 1999), (Gribble & Hertel, 2003) and significant effects (Gribble, Kelly, Refshauge, & Hiller, 2013), (Sabin, Ebersole, Martindale, Price, & Broglio, 2010) after normalization. Another limitation could be the sample size since to produce studies that can detect clinically relevant differences the appropriate sample size has to be determined. However, based on the smallest and largest effect sizes, the sample size can be said to be within an appropriate range for the current study. All the same this should be taken into consideration when interpreting the results. Finally, many COP parameters are reported in the literature; therefore, the choice of COP_tot, COP_ml, and COP_ap might not be enough to allow for a generalization of the results on the reproducibility of the one leg stance test in adolescents with and without back pain.

3.1.6 Conclusion

Static and dynamic postural control test like the one-leg stance test and star excursion balance test show fair to excellent reliabilities in adolescent athletes with and without back pain. Based on the current study population there was no difference in the reliabilities between the healthy athletes and those with back pain.

3.1.7 References

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3.2 Study 2

Is there an association between variables of static and dynamic postural control in adolescent athletes with back pain?

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3.2.1 Abstract

Association between static and dynamic postural control exist in adults with back pain. We aimed to determine whether this association also exist in adolescent athletes with the same condition. 128 athletes with and without back pain performed 3 measurements of 15 seconds of static (one leg stance) and dynamic (star excursion balance test) postural control tests. All subjects and a matched subgroup of athletes with and without back pain were analysed. The smallest center of pressure mediolateral and anterior-posterior displacements (mm) and normalized highest reach distance were the outcome measures. No association was found between variables of the static and dynamic tests for all subjects and the matched group with and without back pain. The control of static and dynamic posture in adolescent athletes with and without back pain might not be related.

Keywords: Postural control, Adolescent athletes, Back pain, one leg stance, Star excursion balance test

3.2.2 Introduction

Postural control (PC) is the ability to maintain the center of mass within the limits of stability (Horak & McPherson, 1996). It is an important requirement for physical and daily activities whether under static or dynamic conditions (Della Volpe, Popa, Ginanneschi, Spidalieri, & Mazzocchio, 2006). The assessment of posture can be carried out statically or dynamically depending on the task performed. In the clinical setting, the assessments are used to evaluate initial deficits resulting from injury, risk of injury and improvement after the intervention for an injury. In the static condition, a force platform or a valid reliable clinical scale can be used (Gribble & Hertel, 2012). It involves standing as still as possible during the performance of one or two leg stance test, followed by assessment of deviations in the location of the center of pressure (COP) measures derived from force plate data (Amiridis, Hatzitaki, & Arabatzi, 2003).

In the general population, static postural assessment can differentiate individuals with back pain from those without back pain (Ruhe, Fejer, & Walker, 2011). The results are however conflicting in the athletic population (Mueller, et al., 2017), (Oyarzo, Villagrán, R.E., Carpintero, & Berral, 2014), (Harringe, Halvorsen, Renström, &

Werner, 2008) with authors recommending a more challenging task, perturbation tests and neuromuscular approach using electromyographic analysis. However, assessing PC using these methods requires an expensive laboratory set-up, advanced technological equipment which are not always readily available (Ruhe, Fejer, & Walker, 2011), (Baratto, Morasso, Re, & Spada, 2002) (Baratto et al. 2002) and challenges in transferring the results to everyday athletic training.

A dynamic test, the star excursion balance test (SEBT) is a simple, inexpensive, rapid, reliable and valid tool for assessing dynamic PC (Hertel, Miller, & Denegar, 2000). It is effective in measuring multi-planar excursion with strong inter-rater and intra-rater reliability measurements (Appiah-Dwomoh E. M., 2018) (Bastien, et al., 2014), (Hertel, Miller, & Denegar, 2000) , responsiveness and criterion validity (Gribble & Hertel, 2003). Performance of the SEBT requires the subject to establish a stable base of support on the stance limb in the middle of a testing grid. The foot is then maintained on the ground firmly whilst performing a maximum excursion of the non-stance limb along the prescribed directions. These are all done without shifting weight on the stance limb or coming to rest on the reaching limb (Gribble, Hertel, & Plisky, 2012), (Gribble & Hertel, 2003). The performance of the SEBT relies largely on the ability to maintain a static, stable and firm balance on the stance limb during both static and dynamic components of the test. In moving the lower limb, the body is required to move the center of mass over the new base of support and safeguard the new position against the disturbance produced by the movement (Hodges & Richardson, 1997). Therefore, it can be assumed that the ability to maintain a static stable base of support on the stance limb during excursion of the non-stance limb in the different directions of the SEBT may determine the distance reached by the non-stance limb.

In back pain subjects, movement of the upper and lower limbs are associated with a delay in the onset of activation of the trunk muscles (Hodges & Richardson, 1997), (Allison, Morris, & Lay, 2008) causing a delay in the stabilization of the spine. Published literature confirms increased COP deviation coupled with reduced performance on the SEBT (Tsigkanos, Gaskell, Smirniotou, & Tsigkanos, 2016) in adults with back pain. This association, if confirmed in athletes will be important as dynamic postural control measurements can also be used in the athletic population with back pain. Therefore, the aim of this study was to determine whether there is an association between displacement of the COP on the stance limbs on the static test and the reach distance of the non-stance limb on the dynamic test in adolescent athletes, with consideration of the back-pain status.

3.2.3 Method

3.2.3.1 Subjects

A total of 128 adolescent athletes (male/female 80/48; 14.5 years; 172.2 cm; 62.3 kg) participated in the study. Subjects were recruited at a health check for adolescent athletes applying to or already in an elite school of sports in a state in Germany. The athletes were from 14 different sports disciplines: boxing (n = 10), athletics (n = 18), rifle shooting (n = 4), rowing (n = 13), canoeing (n = 10), judo (n = 15), football (n = 13), handball (n = 11), cycling (n = 16), wrestling (n = 7), horse riding (n = 1), gymnastics (n = 1), swimming (n = 4) and volleyball (n = 5). The institution's ethics committee gave ethical approval and participants and their parent or guardian gave written informed consent before data collection.

3.2.3.2 Test description and measurement procedure

Anthropometrics, training years, training sessions per week, training minutes per session and type of sports engaged in by subjects were recorded. Afterwards, a standardized back pain questionnaire was used to assess subjective back pain (Ellert, Neuhauser, & Roth-Isigkeit, 2007). The questionnaire consisted of a numeric rating scale in the form of smiley faces 1 (no pain), 2 (little pain), 3 (moderate pain), 4 (strong pain) and 5 (severest pain) (Ellert, Neuhauser, & Roth-Isigkeit, 2007). Pain face 2 is defined as no pain in the current study. All subjects then performed the one leg stance test followed by the SEBT. The first test was conducted by instructing participants to stand on one leg on a force plate (Advanced Mechanical Technology Inc. (AMTI OR6-6), slightly flex the free leg at the hip and knee. The standing leg was slightly flexed at the knee with eyes open. Maintaining their hands on their waist they focused on an imaginary object straight ahead. The testing protocol included 3 repetitions of 15 seconds for each leg. The starting limb was chosen randomly. After the examiner instructed and demonstrated the testing situation, participants were given one practice trial before the main test. Practice and test trials were considered invalid if the participant removed the hands from the waist, dropped down or touched the force plate with the non-standing limb or moved the standing limb.

The SEBT was carried out after the one leg stance test was completed. The shortened version used in this study includes the anterior, posteromedial and posterolateral directions (Appiah-Dwomoh, Müller, Hadzic, & Mayer, 2016). 3 tape measures with a centimetre scale were affixed on the laboratory floor. The first reach direction was aligned anterior to the apex; the other two were oriented 135 degrees to the first in posteromedial and posterolateral directions (Plisky, Rauh, Kaminski, & Underwood, 2006) as shown in Figure 2. Maintaining a single leg stance, participants were instructed to reach out as far as possible with the non-stance limb along the marked tape, point to the most distal portion with their great toe and return the limb back to the starting position (Hertel, Miller, & Denegar, 2000) subjects practiced each direction 4 times before the actual measurement to minimize learning effects (Robinson & Gribble, 2008), (Terry, et al., 2005). This was followed by the recording of 3 successful trials in each direction for both legs, always with a 10-s rest between each test (Terry, et al., 2005). Both limbs were tested, the order of the starting limb was randomized, and the chronology of the directions was defined (1. anterior, 2. posteromedial, 3. posterolateral). The subject's standing foot was placed on the convergence of the reach directional lines of the SEBT (Plisky, Rauh, Kaminski, & Underwood, 2006). In this way the lateral malleolus is positioned at the intersection point of the 3 directions with the foot's longitudinal axis oriented at the anterior direction. The starting position was a bilateral limb stance with feet together. Subjects performed the test with socks on and kept their hands on their hips throughout the testing period. The limb length of subjects in cm was then taken with a measuring tape. This was defined as the distance from the anterosuperior iliac spine to the medial malleolus (Bressel, Yonker, Kras, & Heath, 2007). Maximum reach distance was visually read by the same examiner for all subjects. A trial was considered invalid if the reaching foot did not return to the starting position, touched down while reaching out, the support limb shifted, the heel of the support foot did not stay in contact with the ground or if the hands were removed from the hips.

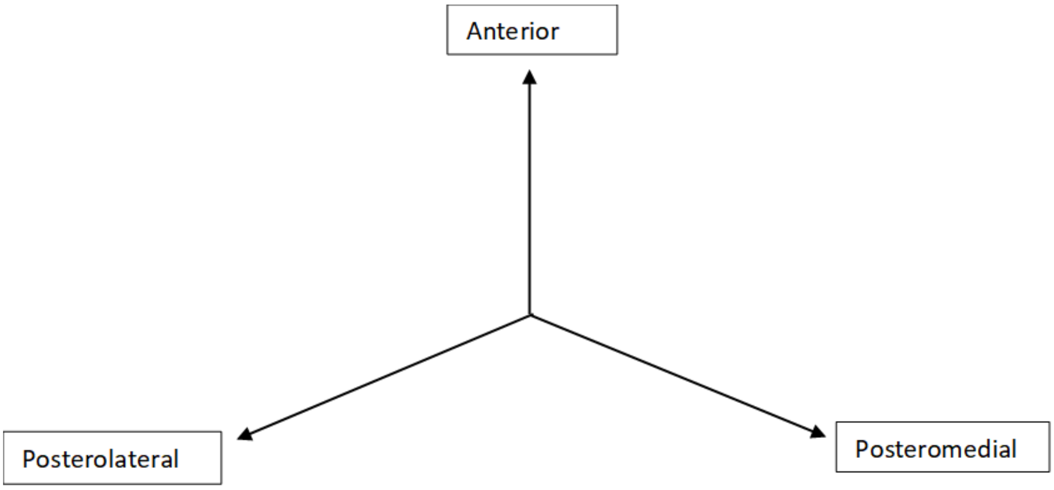

Figure 2: Graphic to show direction of the SEBT

3.2.3.3 Outcome measure and statistical analysis

Displacements of the COP in the mediolateral (COP_ml) and anterior–posterior (COP_ap) directions were recorded with Netforce (AMTI OR6-6). Time series signals were filtered using a Butterworth filter with a cut-off frequency of 12 Hz. The sampling frequency was 1000 Hz and analysis were done for 10s-time interval. Outcome measures of interest were the least of the 3 displacements of the COP_ml, COP_ap and the highest normalized reach distance in the anterior, posteromedial and posterolateral directions for each lower limb. This signified good postural control. For normalization, the highest reach distance of the 3 trials was divided by the limb length (cm) and multiplied by 100 for a percentage score for the SEBT. All subjects were analysed followed by a subgroup analysis of 28 athletes with and without back pain matched to age, sex, training in years, training session per week and training minutes per session.

Data was first descriptively analysed: mean ± standard deviation (SD) and 95% confidence interval (CI). To reduce the variables of the right and left lower limbs into one, dimension reduction was carried out and the Kaiser criteria was used to select one factor for both limbs. Afterwards, Spearman's correlation coefficient was applied to evaluate potential correlations between the static and dynamic PC outcome measures. The strength of the association was interpreted as small ($r = 0.1$), medium ($r = 0.3$) and large ($r = 0.5$) (Cohen 1988). Statistical analysis was carried out using SPSS version 24

(SPSS Inc., IL, USA). To determine whether the research was adequately powered, a post hoc power analysis was carried out using G Power 3.1.9.2 (Faul, Erdfelder, Buchner, & Lang, 2009). The formula used was (mean of back pain group – mean of no back-pain group)/pooled standard deviation of both groups.

3.2.4 Results

The results showed that 77% (n = 98) of the athletes had no pain whilst 16% (n = 21) and 7% (n = 9) had moderate and strong pain respectively. Pain level 5 (severest pain) was not reported by any of the athletes. Anthropometric and training status of all subjects and the matched subgroup are reported in table 1. No association was detected between variables of the static and dynamic postural control for all subjects and the matched group.

Table 8: Anthropometrics and training status of athletes (mean ±SD)

Groups	Pain scale	Sex (m/f)	Prevalence rate (%) (m/f)	Age (yrs)	Height (cm)	Weight (kg)	Training (yrs)	Training (SW)	Training (MS)
No back pain	1	42/22	32.8/17.2	14.4 ± 1.2	173.1 ± 9.1	62.1 ± 11.0	5.8 ± 2.7	7.1 ± 3.0	104.1 ± 25.6
(all subjects)	2	22/12	17.2/9.4	14.6 ± 1.2	172.3 ± 9.1	64.2 ± 12.5	6.1 ± 2.8	8.2 ± 3.7	102.9 ± 30.2
Back pain	3	12/9	9.4/7.0	14.2 ± 1.4	169.1 ± 9.5	58.7 ± 11.5	5.9 ± 3.2	6.4 ± 3.4	119.0 ± 34.5
(all subjects)	4	4/5	3.1/3.9	14.7 ± 1.7	172.5 ± 10.6	64.6 ± 10.3	5.3 ± 2.9	8.3 ± 2.8	112.2 ± 19.9
	5	0/0	0/0	-/-	-/-	-/-	-/-	-/-	-/-
No back pain (matched)		15/13	53.6/46.4	14.1 ± 1.2	170.0 ± 7.8	58.2 ± 8.5	5.7 ± 2.8	6.7 ± 2.9	113.8 ± 25.0
Back pain (matched)		15/13	53.6/46.4	14.1 ± 1.2	168.9 ± 8.9	58.8 ± 9.8	5.8 ± 3.0	6.6 ± 2.9	117.9 ± 31.5

SW (session/week); MS (minutes/session).

Pain scale

No pain = 1&2
Moderate pain = 3
Strong pain = 4
Severest pain = 5

Athletes with back pain obtained larger anterior-posterior displacement values on the static test Table 9.

Table 9: Mean ± SD, lower/upper 95% CI, effect size and p value for the right and left lower limbs for all and matched subjects for the static variables

		Right lower limb			
Group	**Static variables**	**Back pain**	**No back pain**	**Effect size**	**P value**
All subjects	Anterior-posterior displacement	252.3 ± 87.4 (219.7/284.9)	247.6 ± 59.0 (235.8/259.5)	0.063	0.536
	Mediolateral displacement	243.5 ± 66.4 (218.7/268.3)	234.4 ± 58.6 (222.7/246.2)	0.116	0.753
Matched subjects	Anterior-posterior displacement	255.7 ± 88.9 (222.1/290.2)	245.4 ± 63.2 (220.9/269.9)	0.134	0.967
	Mediolateral displacement	245.1 ± 67.4 (219.0/271.2)	224.6 ± 60.7 (201.1/248.1)	0.257	0.302
		Left lower limb			
All subjects	Anterior-posterior displacement	253.6 ± 83.1 (222.6/284.6)	237.5 ± 54.6 (226.6/248.4)	0.176	0.601
	Mediolateral displacement	233.3 ± 68.5 (207.8/248.9)	233.4 ± 51.3 (223.2/243.7)	-0.002	0.992
Matched subjects	Anterior-posterior displacement	256.3 ± 84.4 (223.6/289.0)	238.4 ± 62.4 (214.6/262.1)	0.241	0.566
	Mediolateral displacement	237.2 ± 68.1 (210.8/263.6)	235.9 ± 55.0 (214.9/256.8)	0.021	0.983

Athletes with back pain reached as far as those without pain on the dynamic test although this was not statistically significant (Table 10)

Table 10: Mean ± SD, lower/upper 95% CI, effect size and p value for the right and left lower limbs for all and matched subject for the dynamic variables

		Right lower limb			
	Normalized reach distance (% of limb length)	**Back pain**	**No back pain**	**Effect size**	**P value**
All subjects	**Anterior**	90.0 ± 6.3 (87.7/92.3)	89.3 ± 5.7 (88.2/90.5)	0.174	0.583
	Posteromedial	85.3 ± 9.7 (81.7/88.9)	83.1 ± 7.7 (81.6/84.6)	0.355	0.198
	Posterolateral	81.9 ± 8.1 (78.9/84.9)	80.5 ± 8.0 (78.9/82.1)	0.246	0.41
Matched subjects	**Anterior**	90.1 ± 6.3 (87.7/92.6)	90.0 ± 6.2 (87.6/92.4)	0.023	0.955
	Posteromedial	85.5 ± 9.8 (81.7/89.3)	82.4 ± 7.7 (79.4/85.4)	0.497	0.194
	Posterolateral	82.0 ± 8.1 (78.9/85.2)	79.9 ± 7.0 (77.2/82.6)	0.392	0.296
		Left lower limb			
All subjects	**Anterior**	90.7 ± 6.4 (88.3/93.0)	89.5 ± 6.3 (88.2/90.7)	0.267	0.362
	Posteromedial	84.8 ± 9.5 (81.2/85.1)	83.6 ± 7.8 (82.1/85.2)	0.138	0.497
	Posterolateral	81.3 ± 8.1 (78.3/84.3)	79.9 ± 8.6 (78.2/81.7)	0.237	0.353
Matched subjects	**Anterior**	90.8 ± 6.5 (88.3/93.4)	90.1 ± 6.8 (87.5/92.7)	0.105	0.73
	Posteromedial	85.1 ± 9.3 (81.7/88.8)	82.7 ± 6.9 (80.1/85.4)	0.229	0.275
	Posterolateral	81.1 ± 8.2 (78.0/84.3)	79.0 ± 7.7 (76.1/81.9)	0.264	0.193

3.2.4 Discussion

The main findings of the current study are that: a. there was no correlation between variables of static and dynamic postural control in adolescent athletes with and without back pain; b. Athletes with back pain reached as far as those without pain on the dynamic test with a higher non-statistically significant COP displacement on the static test. The current result contradicts that of (Tsigkanos, Gaskell, Smirniotou, & Tsigkanos, 2016) and (Ganesh GS, 2015). The former researchers reported increased COP deviation with reduced performance on the SEBT (Tsigkanos, Gaskell, Smirniotou, & Tsigkanos, 2016) whilst the latter observed reduced reach distance in back pain subjects compared to their pain free controls. The difference in results could be because the current study involved adolescent athletes aged 12-18 years whilst (Tsigkanos, Gaskell, Smirniotou, & Tsigkanos, 2016) and (Ganesh GS, 2015) worked on an older non-athletic population with an age range of 22-50 years. The sensory and motor resources needed for postural control decline with aging. As such the ability to maintain or restore balance will be affected. Therefore, the older subjects might have utilized larger center of pressure measures and shorter SEBT reach distances to maintain their postural control in the studies. Also, target sway was employed by (Tsigkanos, Gaskell, Smirniotou, & Tsigkanos, 2016) against the lowest anteroposterior and mediolateral displacement of the COP used in the present study. (Ganesh GS, 2015) used dominant and non-dominant limbs whilst (Tsigkanos, Gaskell, Smirniotou, & Tsigkanos, 2016) and the current study used both lower limbs.

The postural control system is made up of sensory (vision, vestibular and proprioceptive systems), central nervous and musculoskeletal systems (Winter, Patla, & Frank, 1990). Proprioceptors provide the central nervous system (CNS) with continuous feedback about the status of each muscle leading to the determination of the positions and movement of body parts (Winter, Patla, & Frank, 1990). According to published literature, dysfunction of sensorimotor pathways due to alteration in the firing time of paraspinal muscles, as occurs in back pain causes delay in muscle response and poor segmental posture (Tsigkanos, Gaskell, Smirniotou, & Tsigkanos, 2016), (Sabin, Ebersole, Martindale, Price, & Broglio, 2010). To compensate for the disturbance and maintain posture, a more stiffing posture using an ankle or hip strategy (Tsigkanos, Gaskell, Smirniotou, & Tsigkanos, 2016) is adopted. There is also the activation of secondary muscles, and an increase in body sway (Tsigkanos, Gaskell, Smirniotou, &

Tsigkanos, 2016). Both trunk and lower extremity muscles are used in the dynamic condition whilst the trunk muscles are used in static conditions (Mouchnino, Aurenty, Massion, & Pedotti, 1992), (Sohn, Lee, & Song, 2013). In a dynamic test like the SEBT the body deals with two distinct challenges. The first is related to displacing the centre of mass over the new base of support with movement of the lower limb (Hodges & Richardson, 1997). The second challenge is concerned with defending this new equilibrium position against the perturbation produced by the movement of the limb (Hodges & Richardson, 1997). As such, the vulnerability of the spine to further injuries would limit how far the limb would move. However, in the current results, the athletes with back pain, although had higher COP displacement values performed as well as those without pain on the SEBT but this was not statistically significant based on observation of the 95% CI. This could be because adolescent athletes have superior balance ability due to sports participation (Nashner, 1982). In addition to this, those with back pain might be more skilled at focusing and attending to important sensory cues when producing refined motor responses (Ganesh GS, 2015) to avoid failure. Therefore, any deficiency in static posture caused by back pain might have been adequately compensated for during the performance of the dynamic test leading to the no association between measures of the static and dynamic PC. Also, although back pain influences the trunk as well as lower limb movement (Hodges & Richardson, Feedforward contraction of transversus abdominis is not influenced by the direction of arm movement, 1997) and a delay in the feed-forward postural response leaves the spine unprotected with limb movement (Hodges & Richardson, 1997), it could be that different neuromuscular mechanisms might be responsible for the regulation of static and dynamic postural control (Hodges & Richardson, 1997) hence the no association observed between the outcome measures of interest. There was no statistically significant difference between the static and dynamic postural control outcome measures for all subjects and the matched group and for the subjects with and without back pain for both lower limbs. This is based on observation of the 95% confidence interval which showed large overlaps. A power analysis based on the lowest (0.002) and largest (0.497) effect sizes showed that approximately 61821 and 21 subjects respectively are needed in both subjects with and without back pain to obtain a statistical power at the level 0.80 (Cohen, 1988).Therefore, based on the smallest and largest effect sizes, the sample size can be said to be within an appropriate range for the current study.

3.2.5 Limitation of study

The pain questionnaire might be a limitation as it assessed pain within the 7 days prior to participation in the study. Hence the possibility of varying phases and location of BP and its effect on the current results cannot be ruled out. Also, it would have been interesting to perform the SEBT on a force plate so there is a direct comparison of COP values from both static and dynamic test in the adolescent athletes. Another limitation of the study is the different sports disciplines considered together. According to (Thorpe & Ebersole, 2008), the SEBT may be sensitive to specific sport related adaptations. The sensorimotor system might also be presented with different challenges due to the different environmental demands needed in the performance of the various sports disciplines (Bressel, Yonker, Kras, & Heath, 2007). In addition to these, different levels of sensorimotor processes might be needed to perform skills of the different sports as well as protect the neuromuscular system from injury. Therefore, these should be taken into consideration during interpretation of the results.

3.2.6 Conclusion

Static and dynamic postural control measured using one leg stance test for the former and SEBT for the later revealed no association in adolescent athletes with back pain. Adolescent athletes with back pain might be using different mechanisms in controlling their static and dynamic posture.

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3.3 Study 3

STAR EXCURSION BALANCE TEST IN YOUNG ATHLETES WITH BACK PAIN

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3.3.1 Abstract

The Star Excursion Balance Test (SEBT) is effective in measuring dynamic postural control (DPC). This research aimed to determine whether DPC measured by the SEBT in young athletes (YA) with back pain (BP) is different from those without BP (NBP). 53 BP YA and 53 NBP YA matched for age, height, weight, training years, training sessions/week and training minutes/session were studied. Participants performed 4 practice trials after which 3 measurements in the anterior, posteromedial and posterolateral SEBT reach directions were recorded. Normalized reach distance was analysed using the mean of all 3 measurements. There was no statistically significant difference ($p > 0.05$) between the reach distance of BP (87.2 ± 5.3, 82.4 ± 8.2, 78.7 ± 8.1) and NBP (87.8 ± 5.6, 82.4 ± 8.0, 80.0 ± 8.8) in the anterior, posteromedial and posterolateral directions respectively. DPC in YA with BP, as assessed by the SEBT, was not different from NBP YA.

Keywords: young athletes; back pain; star excursion balance test

3.3.2 Introduction

Back pain, particularly occurring in the lumbar region, has been considered rare in children and adolescents (Balaqué, Troussier, & Salminen, 1999). However, the most recent studies suggest it is a problem not only in children and adolescents (Calvo-Muñoz, Gómez-Conesa, & Sánchez-Meca, 2013), (Müller, et al., 2016) but also in young athletes (YA) (D'Hemecourt, Gerbino, & Micheli, 2000), (George & Delitto, 2002), (Smith & Sassmannshausen, 2002), (Haus & Micheli, 2012), (Schmidt, Zwingenberger, Walther, & al, 2014), (Schmidt, Zwingenberger, Walther, & al, 2014). Back pain causes a disruption of postural control and can alter trunk muscle activity in chronic (Radebold, Cholewicki, Polzhofer, & Greene, 2001), (Hodges & Richardson, Feedforward contraction of transversus abdominis is not influenced by the direction of arm movement, 1997) and acute (Hodges, Moseley, Gabrielsson, & Gandevia, 2003) patients. Therefore, there is the need for periodic assessment and monitoring, to identify and appropriately rehabilitate the impaired posture and alteration in trunk muscle activity. To evaluate initial deficits resulting from injury, risk of injury and improvement after the intervention for an injury, postural control assessments are used. This can be carried out statically or dynamically depending on the task performed. In the general population, (Ruhe, Fejer, & Walker, 2011), using static measures, confirmed increased postural instability in individuals with low back pain compared to healthy controls. In athletes, however, static assessments are unable to challenge the postural control system and fail to obtain useful information (Harringe, Halvorsen, Renström, & Werner, 2008). Hence, there is a need for dynamic assessment. This form of assessment should involve some level of movement around a base of support and closely replicates the demands of physical activity in sports participation (Gribble & Hertel, 2012). In assessing dynamic postural control (DPC), one test that has captured the attention of researchers and clinicians is the Star Excursion Balance Test (SEBT). Here, DPC is determined by how far a participant can reach while maintaining a base of support (Olmsted, Carcia, Hertel, & Shultz, 2002). It is a simple, inexpensive, reliable tool that does not require special equipment and is effective in measuring multi-planar excursion and postural control (Gribble & Hertel, 2012). The premise of this test is to determine if, while standing on an injured or affected limb to maintain stability, a deficit is produced in the reaching distances, indicating a deficiency in DPC that might be associated with the pathologic condition in the stance limb (Gribble & Hertel, 2012). In people with a history of back pain (BP), there is a delay in the feed-forward postural response leaving the spine unprotected when movement of the lower limb occurs (Hodges & Richardson, 1997). As such, one can assume that the vulnerability of the spine to further injuries would limit how far the limb would move in a dynamic test, such as the SEBT. As BP influences the trunk as well as lower limb movement (Müller, et al., 2016), there is the possibility of detecting deficit in DPC using the measure of reach distance. In the only published article on the use of the SEBT to measure dynamic posture among low back pain subjects in the general population, (Ganesh GS, 2015) concluded that it is an effective tool to identify and measure reach deficits in this group of patients. Therefore, application of this tool in young athletes may prove a more challenging task that could help further assess and monitor DPC deficits in YA with BP. To the best of our knowledge, there is currently no published literature investigating dynamic posture in YA with BP using the SEBT. Therefore, this study aimed to determine if DPC, measured by SEBT reach distance, in YA with BP is different than NBP YA. The hypothesis was that there is a difference in the reach distance in BP and NBP YAs as measured by the SEBT.

3.3.3 Materials and Methods

3.3.3.1 Subjects

A total of 53 YA with BP (14.7 1.2 years, 62.4 13.6 kg, 171.9 10.5 cm, 6.1 2.7 training years, 7.8 ± 3.3 training session/week, 108.5 ± 30.2 training minutes/session) and 53 YA NBP (14.5 ± 1.2 years, 59.6 ± 10.8 kg, 170.5 ± 10.5 cm, 5.7 ± 2.7 training years, 7.8 ± 3.3 training sessions/week, 102.3 ± 28.8 min/session) participated in the study. The athletes were from 13 different sports (boxing, athletics, rifle shooting, rowing, canoeing, judo, football, handball, cycling, wrestling, horse riding, gymnastics and volleyball). The 53 BP subjects were matched with 53 NBP according to age, height, weight, training years, training sessions/week and training minutes/session but not sports discipline. Subjects were recruited at a health check for YA applying to or already in an elite school of sports in Brandenburg, Germany. A pain questionnaire consisting of a numeric rating scale of 1 (no pain) to 5 (most severe pain) in the form of smiley faces was used to allocate participants into control or BP groups (Ellert, Neuhauser, & Roth-Isigkeit, 2007). BP was not confined to a specific back region. Subjects with lower and upper limb injuries, head injuries, vision problems and any other complaints that could have affected balance measurement were excluded. Medical examination was carried out for all subjects before testing. The institution's ethics committee gave ethical approval and the parent or guardian of each participant gave written informed consent before data collection.

3.3.3.2 Test Description

The SEBT is a measure of dynamic balance. The original version is composed of 8 lines extending 45 from the center of a grid made with an adhesive tape on the floor. (Hertel, Braham, Hale, & Olmsted-Kramer, 2006) reported redundancy of some of the directions and proposed a shorter version, which was used in this study. The shortened version includes the anterior, posteromedial and posterolateral directions. Excellent interrater reliability with normalized and non-normalized reach distance scores (Gribble, Kelly, Refshauge, & Hiller, 2013), as well as strong intra-rater reliability (ICC = 0.84–0.87) and test–retest reliability (ICC = 0.89–0.93) (Hertel, Braham, Hale, & Olmsted-Kramer, 2006), have been reported. There is also literature to support the construct and predictive validity of the SEBT (Olmsted, Carcia, Hertel, & Shultz, 2002), (Hertel, Miller, & Denegar, Intratester and intertester reliability during the Star

Excursion Balance Tests., 2000), although no gold standard exists for measuring dynamic balance.

3.3.3.3 Measurement Procedure

Age, gender, weight, height, number of training years, training days per week, training minutes per session and type of sports engaged in by subjects were recorded. Oral instructions, as well as a demonstration of how the test should be performed, were given to the participants. The SEBT directions were constructed by affixing 3 tape measures with a centimetre scale on the laboratory floor. The first reach direction was aligned anterior to the apex; the other two were oriented 135° to the first in posteromedial and posterolateral directions (Coughlan, Fullam, Delahunt, Gissane, & Caulfield, 2012). The order of the starting limb was randomized, and the chronology of the directions was defined (1. Anterior; 2. Posteromedial; 3. Posterolateral). The subject's starting foot is placed at the convergence of the reach directional lines of the SEBT (Coughlan, Fullam, Delahunt, Gissane, & Caulfield, 2012). In the process the lateral malleolus is positioned at the intersection point of the 3 directions with the foot's longitudinal axis oriented at the anterior direction. The starting position is a bilateral stand. Subjects stood with socks while keeping their hands on their hips. Maintaining a single leg stance, they were instructed to reach out as far as possible with the non-stance limb along the marked tape, point to the most distal portion with their great toe and return the limb back to the starting position (Plisky, Rauh, Kaminski, & Underwood, 2006). Subjects practiced each direction 4 times before the main test to minimize learning effect (Hertel, Miller, & Denegar, Intratester and intertester reliability during the Star Excursion Balance Tests., 2000), (Robinson & Gribble, 2008). This was followed by the recording of 3 successful trials in each direction for both legs, always with a 10-seconds rest between each test (Hertel, Braham, Hale, & Olmsted-Kramer, 2006). The limb length of subjects was then taken with a measuring tape. This was defined as the distance from the anterosuperior iliac spine to the medial malleolus (Terry, et al., 2005). Maximum reach distance was visually read by the same examiner for all subjects. The examiner is a final year doctoral student with 5 years working experience as a physiotherapist and 4 additional years of working with young athletes as part of the doctoral studies. Prior to testing the examiner received training at the University of Potsdam Outpatient Clinic, a licensed medical examination center of the German Olympic Sports federation. A trial was considered invalid if the reaching foot did not return to the starting position, touched down while reaching out, the support limb shifted, the heel of the support foot did not stay in contact with the ground or if the hands were removed from the hip (see Figure 3).

Figure 3: Testing situation: Star Excursion Balance Test in the anterior, posterolateral and posteromedial directions

3.3.3.4 Outcome Measure

Outcome measures of interest were the mean normalized reach distance of the 3 trials, and a composite reach distance score (CRDS) (Holden, Boreham, Doherty, Wang, & Delahunt, 2014). For normalization, the mean reach distance of the 3 trials was divided by limb length (cm) and multiplied by 100 for a percentage score. The composite reach distance was calculated using the sum of the 3 normalized reach distances divided by 3 times the limb length, multiplied by 100 (Holden, Boreham, Doherty, Wang, & Delahunt, 2014).

3.3.3.5 Data and Statistical Analysis

Relevant data for analysis was handwritten into a case report form after which computation was performed. Data was first descriptively analysed (mean ± standard deviation), followed by independent t-tests, paired t-tests and Mann-Whitney U tests for normally and non-normally distributed data, respectively. Post hoc power analysis was carried out using G*Power 3.1.9.2 [29] to determine whether the research was adequately powered. Effect size was calculated using the formula (mean of BP group—mean of NBP group)/pooled standard deviation of both groups. SPSS version 22 (SPSS Inc., Chicago, IL, USA) was used for analysis. Significance was set at = 0.05.

3.3.4 Results

Normalized reach distances for BP and NBP groups in each direction and composite reach distance scores (CRDS) for right lower limb (RLL) and left lower limb (LLL), are presented in Table 11 and Table 12 . There was no significant difference between the RLL and LLL of BP and NBP subjects for the reach distances and the CRDS.

Table 11: Normalized Reach Distance, Composite Reach Distance Score (CRDS) and limb length (cm) (mean± sd) for BP subjects.

Normalized Reach Distance (Limb Length %) for BP Subjects			
	RLL	**LLL**	**P value**
Anterior	87.2 ± 5.3	87.7 ± 5.8	0.27
Posteromedial	82.5 ± 8.2	82.6 ± 7.9	0.86
Posterolateral	78.7 ± 8.1	77.7 ± 8.0	0.06
CRDS	91.2 ± 10.1	90.9 ± 9.8	0.53
Limb length (cm)	91.3 ± 6.3	91.4 ± 6.3	0.37

Table 12: Normalized Reach Distance, CRDS and limb length (cm) (mean ± sd) for NBP subjects.

Normalized Reach Distance (% Limb Length) for NBP Subjects			
	RLL	**LLL**	**P value**
Anterior	87.8 ± 5.6	88.3 ± 6.2	0.22
Posteromedial	82.4 ± 8.0	82.1 ± 8.6	0.53
Posterolateral	80.0 ± 8.8	79.2 ± 8.2	0.19
CRDS	91.9 ± 10.8	91.8 ± 11.1	0.81
Limb length (cm)	91.3 ± 6.4	91.3 ± 6.5	0.63

There was no statistically significant difference between BP and NBP subjects for the RLL in all directions of the SEBT. The effect sizes for the reach distances were small (see Table 13).

Table 13: Normalized Reach Distance (% limb length), CRDS (mean ± sd) and effect size for the RLL of subjects.

Normalized Reach Distance (% of Limb Length) for RLL				Effect Size
	BP	**NBP**	**P value**	
Anterior	87.2 ± 5.3	87.8 ± 5.6	0.63	0.11
Posteromedial	82.5 ± 8.2	82.4 ± 8.0	0.65	0.01
Posterolateral	78.7 ± 8.1	80.0 ± 8.6	0.44	0.16
CRDS	91.2 ± 10.1	91.9 ± 10.8	0.75	0.07

The population means of the RLL for the BP and NBP young athletes did not show significant evidence of a difference as observed from the 95% confidence interval (Figure 4 to Figure 7).

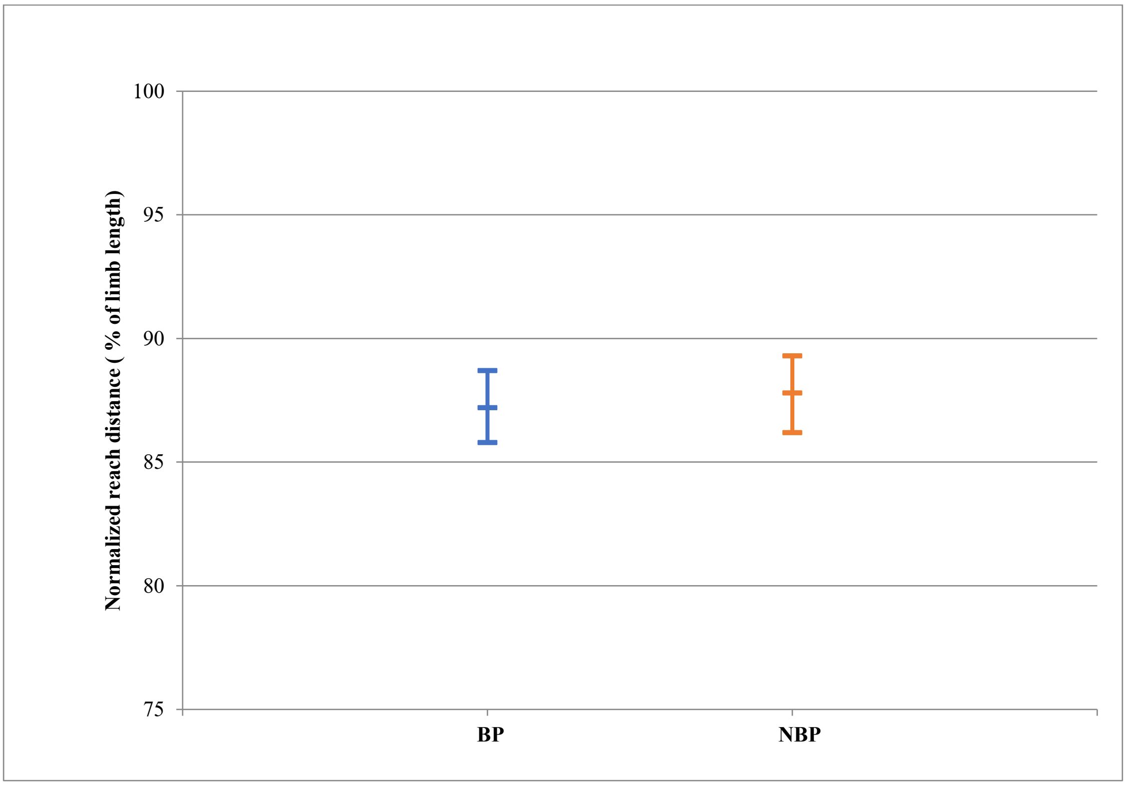

Figure 4: Anterior Reach Distance for RLL (Mean and CI 95%)

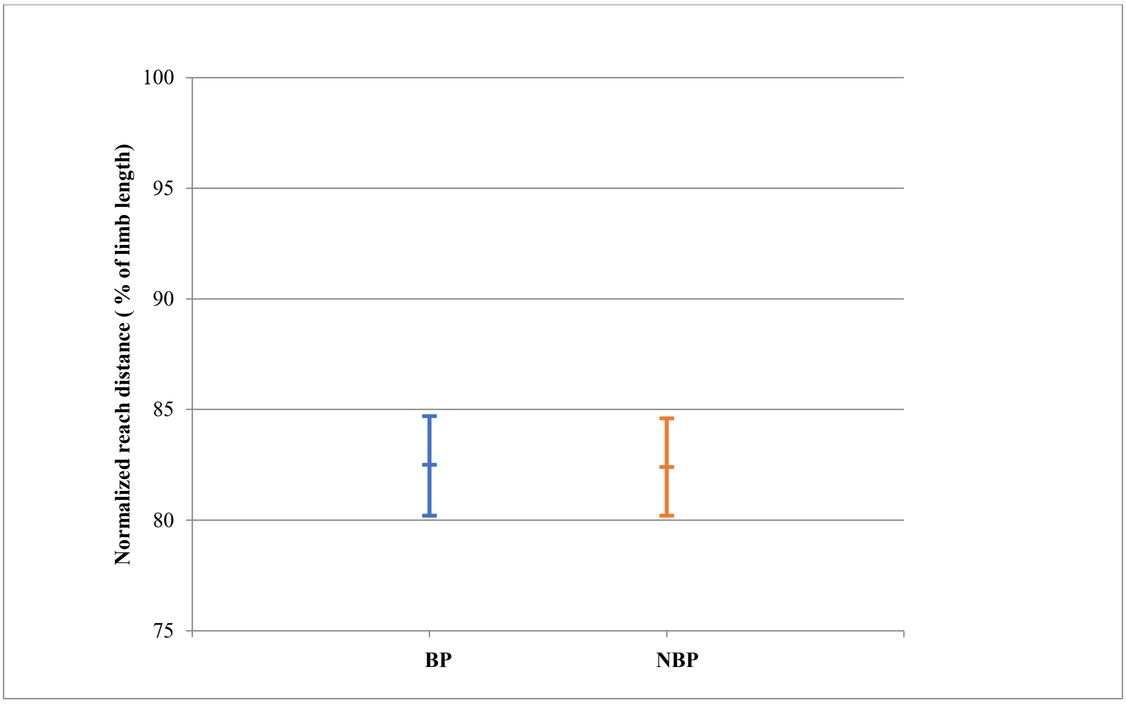

Figure 5: Posteromedial reach distance for RLL (Mean and CI 95%)

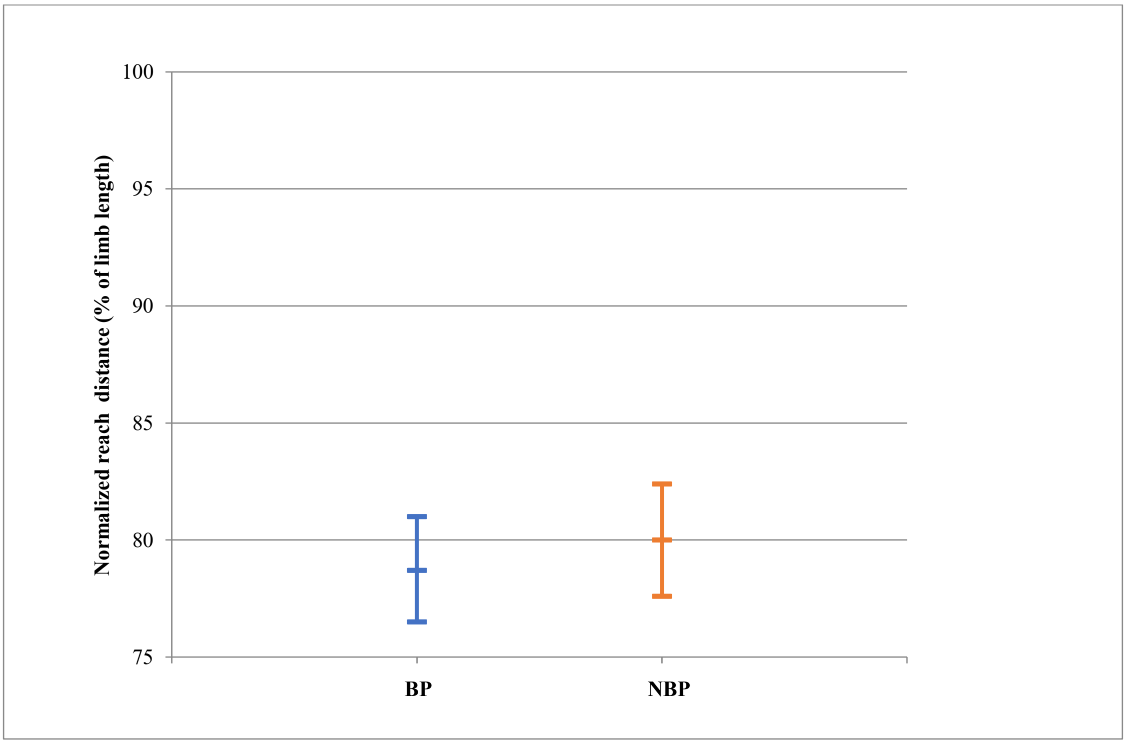

Figure 6: Posterolateral reach distance for the RLL (Mean and CI 95%)

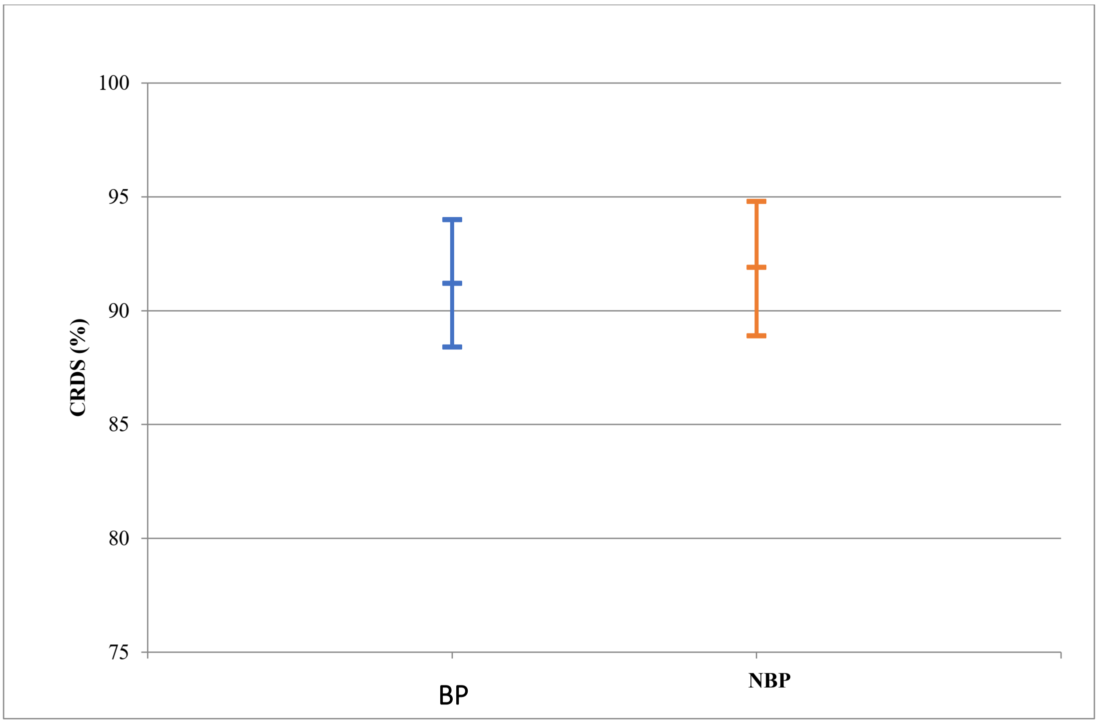

Figure 7: CRDS for the RLL (Mean and CI 95%)

The reach distances and CRDS of the LLL for BP were not statistically significantly different from the NBP subjects. The effect sizes for the reach distances were also small (see Table 14).

Table 14: Normalized Reach Distance (% of limb length), Composite Reach Distance Score (CRDS) and effect size for the LLL of subjects.

Normalized Reach Distance (% of Limb Length) for LLL				Effect Size
	BP	**NBP**	**P value**	
Anterior	87.7 ± 5.8	88.3 ± 6.2	0.61	0.10
Posteromedial	82.6 ± 7.9	82.1 ± 8.6	0.79	0.06
Posterolateral	77.7 ± 8.0	79.2 ± 8.2	0.41	0.25
CRDS	90.9 ± 9.8	91.8 ± 11.1	0.68	0.09

There was also no significant evidence that the population means of the LLL for the BP and NBP young athletes are different as shown by the 95% confidence interval (Figure 8 to Figure 11).

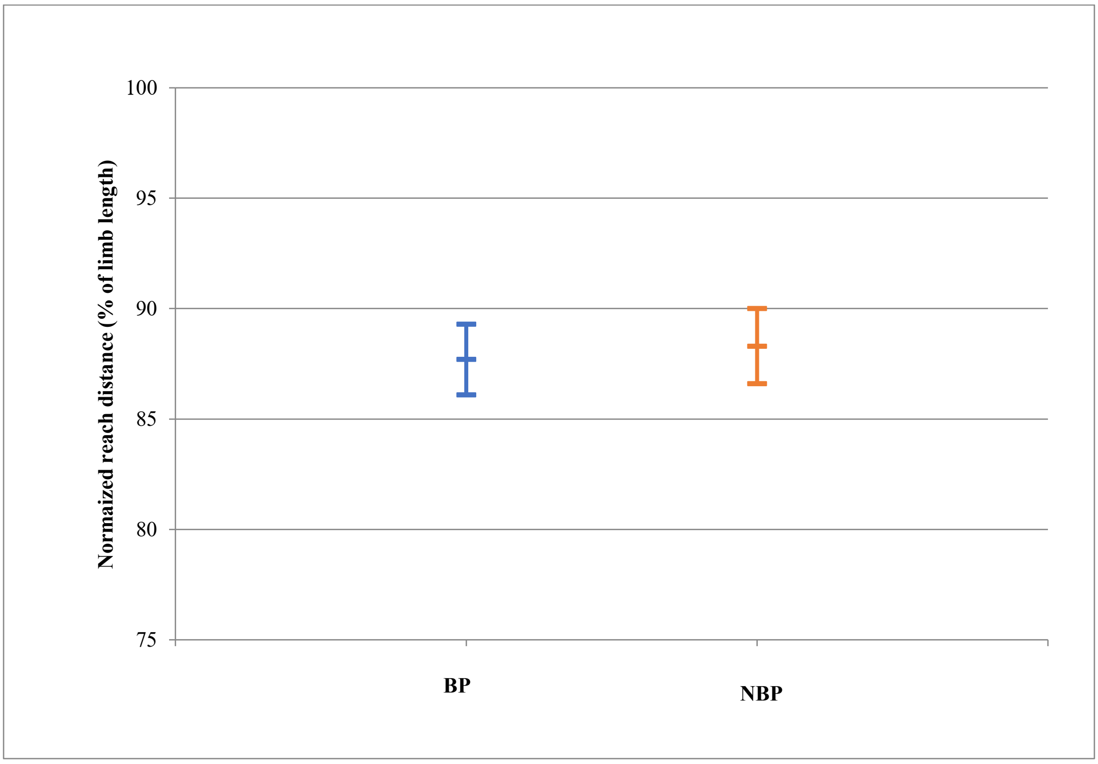

Figure 8: Anterior Reach Distance for LLL (Mean and CI 95%)

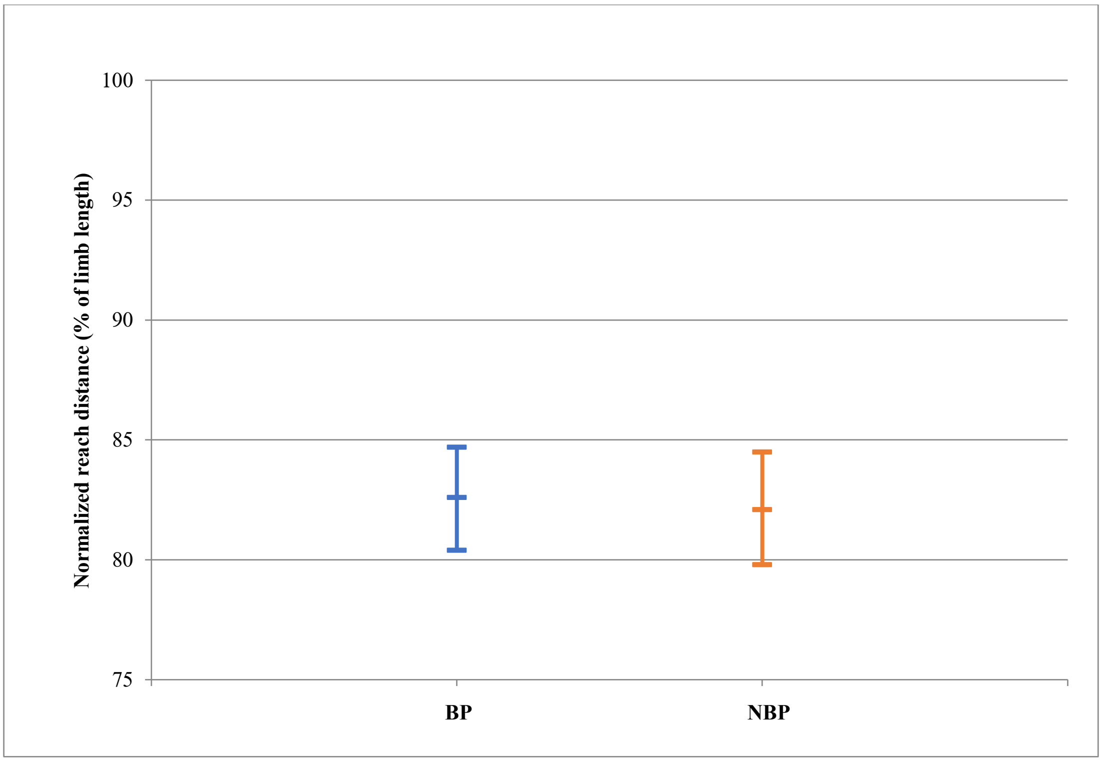

Figure 9: Posteromedial reach distance for LLL (Mean and CI 95%)

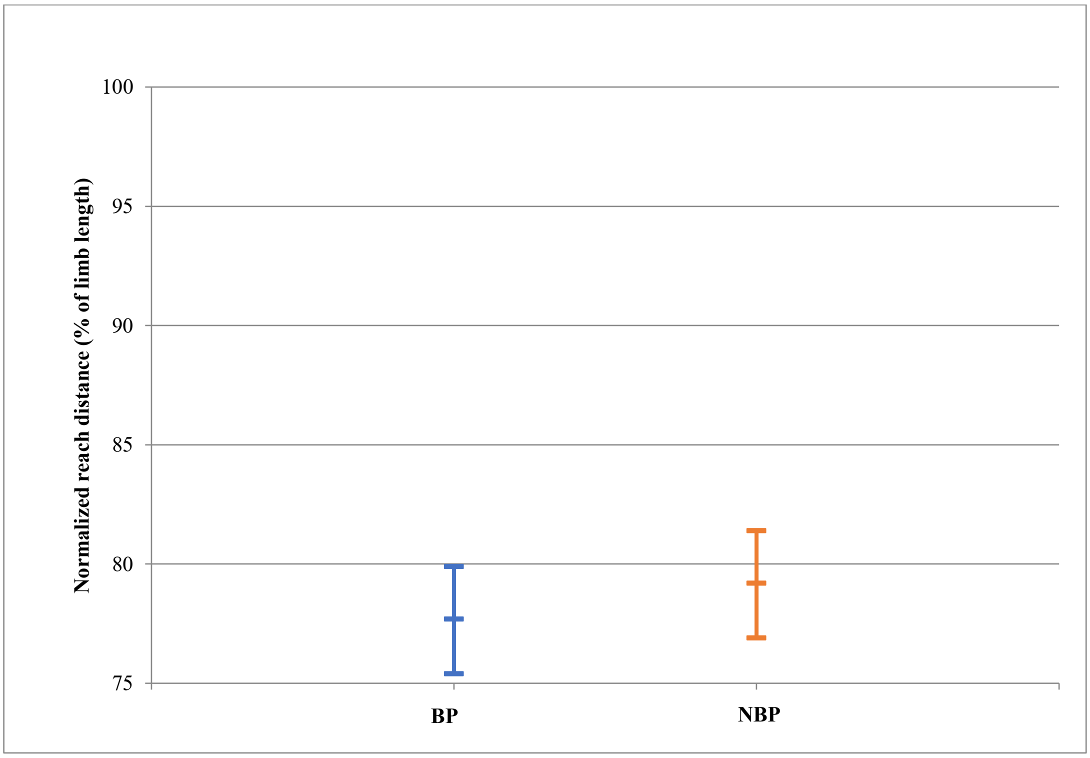

Figure 10: Posterolateral reach distance for the RLL (Mean and CI 95%)

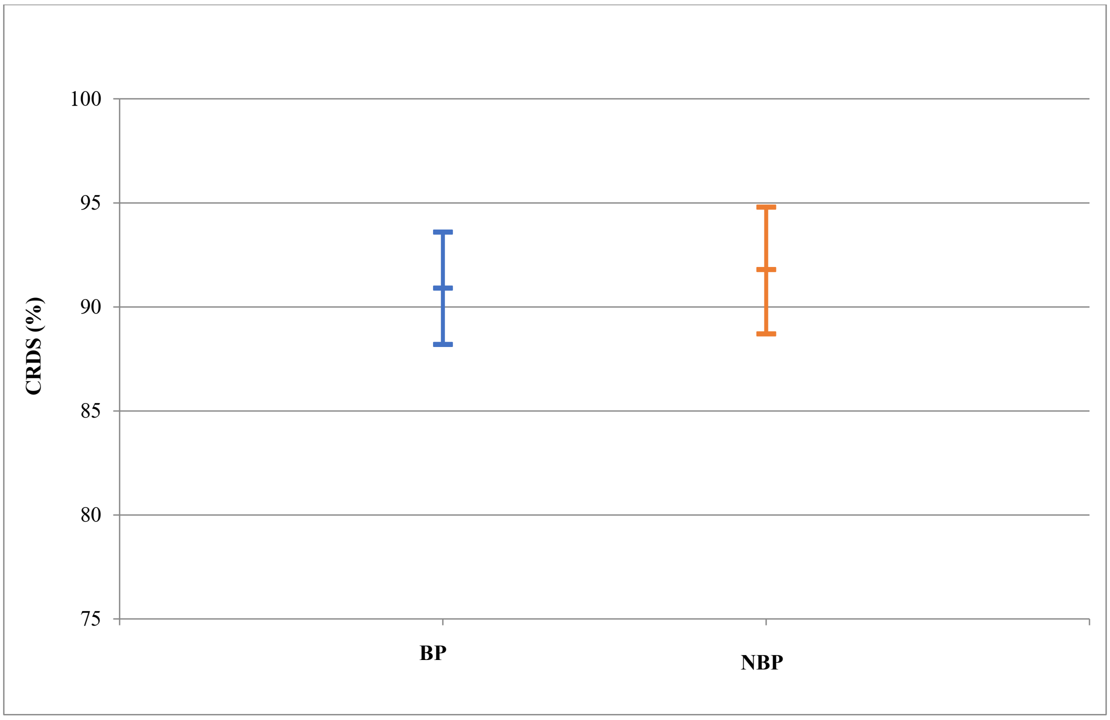

Figure 11: CRDS for the LLL (Mean and CI 95%).

3.3.5 Discussion

This study aimed at determining if dynamic postural control, as measured by normalized SEBT reach distances, differed between YA with and without BP. The human postural system operates based on integrated information from three independent sensory sources: visual, vestibular and somatosensory (Massion, 1992). For the body to maintain balance it relies on rapid, continuous feedback from these sensory sources to execute smooth and coordinated neuromuscular actions (Nashner, 1982). Therefore, damage to sensory tissues and pain inhibition in the lumbar spine and trunk, as occurs in BP, are believed to affect the postural control mechanism (Radebold, Cholewicki, Polzhofer, & Greene, 2001), (Brumagne, Cordo, Lysens, Verschueren, & Swinnen, 2000). This leads to the adoption of alternative postural control strategies to cope with the new demands introduced by pain (Radebold, Cholewicki, Polzhofer, & Greene, 2001). This could be why the BP subjects performed as well as the controls in all directions. It could also be that athletes generally have superior balance ability due to sport participation (Hrysomallis, 2011) masking the effects of pain on balance. In addition to this, the visual system provides the body with visual cues for use as reference points in orienting the body in space. It also provides feedback from the reach leg during movement and allows observation of scored reach distances (Coughlan, Fullam, Delahunt, Gissane, & Caulfield, 2012). This also could have contributed to the present result in which the BP YA reached as far as their matched controls. In a dynamic task such as the SEBT, visual and vestibular inputs are important and tend to be the most reliable (Latash, 1998) . However, a reduction in vision feedback (Latash, 1998) that should occur during the posteromedial and posterolateral reaches still did not alter reach distances between the two groups of interest. According to (Jacobs, Henry, Jones, Hitt, & Bunn, 2011), there is reduced proprioceptive feedback from mechanoreceptors of the trunk and hip joint because of altered sensory input at the site of BP. Hence one would have thought this would lead to a differentiation between the BP subjects and their matched controls. The current results could thus be a confirmation that athletes are indeed more skilled at focusing and attending to important sensory cues, when producing refined motor responses (Ashton-Miller, Wojtys, Huston, & Fry-Welch, 2001), like those during the SEBT.

The only published literature on SEBT in relation to BP is that of (Ganesh GS, 2015). Unlike the present study, they showed a statistically significant difference between low back pain and control subjects. Their back-pain subjects reported lower anterior (72.61 ± 6.91), posteromedial (74.19 ± 8.50) and posterolateral (63.19 ± 1.18) reach distances compared to the present study, 87.2 ± 5.3, 82.5 ± 8.2 and 78.7 ± 8.1 for the same directions respectively. The control subjects of Ganesh et al. (2015) also recorded lower anterior (82.38 ± 5.11) and posterolateral (76.30 ± 9.32) but higher posteromedial (83.06 ± 1.02) reach distances compared to the current study of 87.8 ± 5.6, 82.4 ± 8.0 and 80.0 ± 8.6 for the anterior, posteromedial and posterolateral reach distances, respectively. This result adds to the knowledge that athletes generally have superior balance ability compared to the general population (Hrysomallis, 2011). Our results, however, cannot be compared directly to the above-mentioned study due to different study populations, severity of BP and limb tested. Young athletes (age range 12–18) were measured in this study, while (Ganesh GS, 2015) measured non-athletes with an age range of 22–50 years.

There was no significant difference between the right and left lower limbs of young athletes with and without back pain on all the reach distances of the SEBT and the CRDS. The current result, though it confirms the findings of (Holden, Boreham, Doherty, Wang, & Delahunt, 2014) and (Alonso, Brech, Bourquin, & Greve, 2011), cannot be directly compared. The investigations mentioned above worked on the dominant and non-dominant limbs of athletes (13 ± 0.3 years) and non-athletes (26 ± 5.0 years) respectively while the current one did not take limb dominance into consideration. In interpreting the above results, gender was not taken into consideration. There is lack of agreement on the effect of gender on the SEBT, with literature reporting no effects (Holden, Boreham, Doherty, Wang, & Delahunt, 2014), (Bressel, Yonker, Kras, & Heath, 2007), (Gribble & Hertel, 2003) and significant effects (Gribble, Kelly, Refshauge, & Hiller, 2013), (Sabin, Ebersole, Martindale, Price, & Broglio, 2010) after normalization. Hence further investigation is required to ascertain the effect of gender on the current results.

The 95% confidence intervals for all the reach distances and CRDS for both BP and NBP subjects include the null hypothesis means and showed large overlaps. Hence the conclusion can be drawn that there is no statistically significant difference between the reach distances of BP and NBP young athletes for both RLL and LLL. Finally, because of the sample size (N = 53), limited statistical power may have played a role in limiting the significance of the reach distances between the BP and NBP groups. Power analysis showed that based on the lowest effect size observed in the present study (d = 0.01), approximately 123,652 subjects would be needed in both BP and NBP groups to obtain statistical power at level 0.80 (Cohen, 1988). Therefore, this supports the results showing no differences.

3.3.5.1 Limitations of the Study

The pain questionnaire may be considered a limitation of this study as it only assessed pain within the 7 days prior to participation in the study. Hence, the possibility of varying phases and location of BP and its effect on the current results cannot be ruled out. In addition to this, a mean pain score of 2.6 for our cohort might be too low to produce differences. Another limitation might be the varying sports disciplines considered together in the study. It would have been interesting to focus on the major sports discipline presented by our athletes, as according to (Thorpe & Ebersole, 2008), the SEBT may be sensitive to specific sport related adaptations. Also, distinct skill requirements and environmental demands of different sports likely pose different challenges to the sensorimotor systems (Bressel, Yonker, Kras, & Heath, 2007). Accordingly, each sport will likely require different levels of sensorimotor processes to perform skills as well as protect the neuromuscular system from injury (Bressel, Yonker, Kras, & Heath, 2007) . Consequently, any differences that might have been present could have been masked due to the various sports disciplines involved in this study.

3.3.6 Conclusions

YA with and without BP do not differ in reach distance as measured on the SEBT. Hence, deficits in dynamic postural control, because of BP, could not be assessed using the SEBT reach distance. Therefore, our hypothesis is rejected. This may imply that the SEBT, although a simple tool, is not effective in discriminating between YA with and without BP. Future studies should use questionnaires that assess BP longer than the previous 7 days and consider specific BP classification. Investigations comparing young athletes from different sports disciplines would be interesting.

3.3.7 References

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4. General Discussion

The purpose of this thesis was to determine whether the one leg stance test as a measure of static PC and SEBT a measure of dynamic PC could be used to detect deficits in static and dynamic postural control in adolescent athletes with and without back pain. The results of this thesis revealed that the one leg stance test and the SEBT are reproducible static and dynamic postural control tests which can be used in adolescent athletes with and without back pain. However, these tests cannot be used to detect deficit in postural in this group of athletes because there is no association between the outcome measures. Also, no statistically significant difference exists between the static and dynamic posture of the adolescent athletes in these tests. Postural control is one of the factors used to determine deficits in back pain (Ruhe, Fejer, & Walker, 2011). Published literature shows that adults suffering from back pain have reduced postural control (Ruhe, Fejer, & Walker, 2011), (Tsigkanos, Gaskell, Smirniotou, & Tsigkanos, 2016) using the one leg stance test and the SEBT. These results cannot be assumed to be the same in adolescent athletes because the reproducibility of these test have first not been tested.

The results of this thesis showed that in adolescent athletes with and without back pain, the reproducibility of static postural control using one leg stance test is fair to good whilst that for the dynamic posture using the SEBT is good to excellent. Also, there was no statistically significant difference between the reproducibility of the static and dynamic tests, as well as between subjects with and without back pain. The reproducibility result of the one leg stance test adds to the various center of pressure parameters reported to be reliable in literature (Goldie, Evans, & Bach, 1992), (Harringe, Halvorsen, Renström, & Werner, 2008) , (De Kegel, et al., 2011), (Ruhe, Fejer, & Walker, 2011), (Muehlbauer, Roth, Mueller, & Granacher, 2011). Whilst that of the SEBT are in the range of that reported in published literature (Kinzey & Armstrong, 1998), (Hertel, Miller, & Denegar, 2000), (Brumagne, Cordo, Lysens, Verschueren, & Swinnen, 2000), (Calatayud, Borreani, Colado, Martin, & Flandez, 2014). Postural control deficits become more evident during the performance of tasks that are challenging like the one leg stance test and the SEBT. Athletes have superior balance due to repetitive training (Bressel, Yonker, Kras, & Heath, 2007), and a one leg stance is often required to switch from two legs to one during the performance of sports, thus requiring both the static and dynamic component of posture. Hence, the more challenging static one leg stance test and the SEBT which is dynamic in nature are the appropriate assessment measures for adolescent athletes with and without back pain. The finding of a no difference between the static and dynamic tests, as well as between subjects with and without back pain could be because athletes with back pain adopt alternative postural control strategies to cope with pain (Radebold, Cholewicki, Polzhofer, & Greene, 2001) and this more so with a young study population. (Bressel, Yonker, Kras, & Heath, 2007) reported that athletes from different sports performed differently on both static and dynamic postural control measures. They concluded that specific trainings in sport may cause different static and dynamic adaptations. Therefore, any difference that could have been observed between tests and subject groups might have been masked by the incorporation of different sports disciplines in the study sample. This notwithstanding, the current investigation supports the use of the one leg stance and the SEBT in adolescent athletes with and without back pain since it has been proven to be reproducible. These tests can therefore be used without taking into consideration back pain injury.

In performing the dynamic postural control test, one is required to establish a stable base of support on the stance limb in the middle of a testing grid. The foot is then firmly maintained on the ground whilst performing a maximum excursion of the non-stance limb along prescribed directions (Gribble & Hertel, 2012), (Gribble & Hertel, 2003). The assumption was that the ability to maintain a static stable base of support on the stance limb (static postural control) during excursion of the non-stance limb (dynamic postural control) may determine the distance reached by the non-stance limb during the performance of the test. Also, back pain influences the trunk as well as lower limb movement (Müller, et al., 2016) and feedback from the reach leg to the sensory sources of the postural control system are interrupted during performance of the SEBT (Coughlan, Fullam, Delahunt, Gissane, & Caulfield, 2012). Therefore, there is the possibility of detecting deficits in postural control using the measure of displacement from the static postural test and reach distance from the dynamic test. In published literature, it is reported that increased center of pressure deviation, which signifies weaker static postural control is associated with reduced performance on the SEBT (Tsigkanos, Gaskell, Smirniotou, & Tsigkanos, 2016) in adults with back pain. This association, if confirmed in the adolescent athletes with and without back pain will be important as dynamic postural control measurements can then be used in the athletic population to detect deficit in postural control. With the establishment of the reproducibility of the postural control tests in the study population, association between the static and dynamic postural tests was determined. It was also determined whether this association will lead to the differentiation of adolescent athletes with back pain from those without back pain.

The results obtained contradicted our assumption and other published studies mainly due to the characteristics of the study population (Tsigkanos, Gaskell, Smirniotou, & Tsigkanos, 2016), (Ganesh GS, 2015). Integrated information from three independent sensory sources: visual, vestibular and somatosensory operates the human postural system (Massion, 1992). For the body to maintain balance it relies on rapid, continuous feedback from these sensory sources to execute smooth and coordinated neuromuscular actions (Nashner, 1982). In a dynamic test like the SEBT the body deals with two distinct challenges. The first is related to displacing the center of mass over the new base of support with movement of the lower limb (Hodges & Richardson, 1998). The second challenge is concerned with defending this new equilibrium position against the perturbation produced by the movement of the limb (Hodges & Richardson, 1997). Therefore, damage to sensory tissues and pain inhibition in the lumbar spine and trunk, as occurs in BP, will affect the postural control mechanism (Radebold, Cholewicki, Polzhofer, & Greene, 2001), (Brumagne, Cordo, Lysens, Verschueren, & Swinnen, 2000). This in turn will lead to the adoption of alternative postural control strategies to cope with the new demands introduced by pain (Radebold, Cholewicki, Polzhofer, & Greene, 2001). Also, the vulnerability of the spine to further injuries would limit how far the limb would move. However, in the current results, the athletes with back pain, although they had higher non statistically significant COP displacement values signifying weaker postural control, performed as well as those without pain on the SEBT. The visual system provides the body with visual cues for use as reference points in orienting the body in space. It also provides feedback from the reach leg during movement and allows observation of scored reach distances (Coughlan, Fullam, Delahunt, Gissane, & Caulfield, 2012). Visual and vestibular inputs are important and tend to be the most reliable (Latash, 1998) in a dynamic task such as the SEBT. However, a reduction in vision feedback (Latash, 1998) that should occur during the posteromedial and posterolateral reaches still did not alter reach distances between the two groups of interest. Also, there is reduced proprioceptive feedback from mechanoreceptors of the trunk and hip joint as a result of altered sensory input at the site of the back pain (Jacobs, Henry, Jones, Hitt, & Bunn, 2011). Hence one would have thought this would lead to a differentiation between the back pain subjects and their matched controls. The current results could thus be a confirmation that athletes are indeed more skilled at focusing and attending to important sensory cues, when producing refined motor responses (Ashton-Miller, Wojtys, Huston, & Fry-Welch, 2001) like those during the SEBT. It could also be that athletes generally have superior balance ability due to sport participation (Hrysomallis, 2011) masking the effects of pain on balance. In addition to this, adolescent athletes with and without back pain might be using different mechanisms in controlling their static and dynamic posture. This could imply that the one leg stance test and the SEBT are not effective in discriminating between adolescent athletes with and without back pain. Therefore, the ability of the tests to accomplish their goal in our study population needs to be questioned. This is because published literature confirms the ability of the one leg stance test and SEBT to discriminate between individuals with and without lateral ankle sprain (Bastien, et al., 2014), back pain (Ganesh GS, 2015) and lower limb injury (Plisky, Rauh, Kaminski, & Underwood, 2006).

The results of this thesis should be interpreted taking into consideration the limitation imposed by the pain questionnaire. It assessed pain within the 7 days prior to participation in the study. Therefore, the varying location and phases of the pain at the back and its effect on the current results cannot be ruled out. In addition to this, the mean back pain score of the subjects might have been too low to produce a difference between the subjects of interest. Further studies involving adolescent athletes with the same location and phase of back pain will provide additional information on the area of the back more prone to pain and its effect on postural control in the athletes. The different sports disciplines of the athletes involved in the studies can be considered as another limitation. This is because the SEBT may be sensitive to specific sport related adaptations (Thorpe & Ebersole, 2008). Therefore, future studies should focus on the major or individual sports disciplines involved in by the athletes in order not to mask any differences that might be present. In addition to this, the SEBT could be performed on a force plate so there is a direct comparison of the centre of pressure values for both static and dynamic test. The effect of gender on the results of this thesis needs to be further investigated due to the lack of agreement on the effect of gender on the SEBT

(Sabin, Ebersole, Martindale, Price, & Broglio, 2010), (Gribble & Hertel, 2003), (Bressel, Yonker, Kras, & Heath, 2007), (Fleiss, 1999). This limitation can be addressed by further analysing data from the current thesis taking into consideration the gender of the athletes. In determining the reproducibility of the tests, the sample size might be considered as a limitation. This is because the appropriate sample size must be determined to produce studies that can detect clinically relevant differences. However, the sample size can be said to be within an appropriate range based on the smallest and largest effect sizes. All the same this should be taken into consideration when interpreting the results. Finally, the choice of COP_tot, COP_ml, and COP_ap might be a limitation for the static test as many COP parameters are reported in the literature. Therefore, these would not be enough to allow for a generalization of the results on the study on reproducibility. Further studies using other COP parameters will add information to the current ones used in this thesis.

The present thesis established that the postural control tests can be used in adolescent athletes with and without back pain. Also, these tests can be used in adolescent athletes without considering pain at the back. The outcome measures used in the thesis are not challenging enough to detect deficit in postural control in adolescent athletes with and without back pain. For future investigation, gender and the type of sports engaged in by the athletes needs to be taken into consideration. Also, other outcome measures, which focus on other areas apart from displacement and distance can could be included.

5. Conclusion

The thesis reveals that the static (one leg stance test) and dynamic postural tests (SEBT) are reproducible, therefore they can provide clinicians, sports teachers and coaches with reproducible tools for testing the static and dynamic posture of adolescent athletes with and without back pain. These tests however do not correlate each other, are unable to differentiate between the adolescents with and without back pain and between static and dynamic postural control. This might imply that the various limitations discussed in the thesis contributed to the ineffectiveness of these tests, the that adolescent athletes might be using different mechanisms to control their static and dynamic posture making them unrelated or the tests might not be measuring what they are supposed to measure.

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Appendix

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Abbreviations

AMTI: Advanced Mechanical Technology, Inc

BP: Back pain

CNS: Central nervous system

COP: Centre of pressure

COP_ap: anterior-posterior displacement of the COP

COP_ml: medio-lateral displacement of the COP

CI: confidence interval

CRDS: composite reach distance

DPC: dynamic postural control

ICC: intraclass correlation coefficient

NBP: subject without back pain

PC: postural control

SEBT: star excursion balance test

YA: young athletes

Authors' contribution

The present thesis is designed as a cumulative dissertation. In this regard, three scientific articles
have been prepared, submitted to peer-reviewed journals, and accepted for publication.
According to the local doctoral degree regulations (§ 7 (4), sentence No. 2), significant contributions
to the articles from the respective co-authors were acknowledged and finally confirmed by each co-author:

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Chap. 3.2	**EKAP**, SM, FM	**EKAP**	**EKAP**	**EKAP**, SM	**EKAP**, SM, FM
Chap 3.3	**EKAP**, SM, FM	**EKAP**, MH	**EKAP**	**EKAP**, SM, MH	**EKAP**, SM, MH, FM

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