The Single Leg Squat Test in the Assessment of Musculoskeletal Function: a Review

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Abstract

Contemporary evidence shows the Single leg squat has evolved into a functional test and is now being used clinically by some practitioners. This review describes the evolution of the Single leg squat test and its role within the examination of musculoskeletal function. It examines the evidence relating clinical assessment using the Single leg squat test to the mechanics of walking and discusses the possible outcomes of the Single leg squat test and its interpretation. Papers were obtained through a search of electronic databases cinahl, medline, science direct, sport discus and ovid from inception, with various combinations of the terms "Single leg," "Squat," "Dip," "Pelvis", "Stability" and "Test." An additional manual search was made of relevant bibliographies without limitation for year of publication.

Keywords: Single leg squat test, clinical test, gait.

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INTRODUCTION

Squatting using both legs, the double leg squat, was first reported as part of closed chain knee rehabilitation in the 1990s.[1] Double leg squats were progressed into single leg squats as part of exercise progression. The first paper to describe the Single leg squat was published by Chris Benn, a student physical therapist, at the University of Rhode Island, United States of America in 1998(1). Benn used the single leg squat within his study to compare two knee strengthening regimes. He concluded that using Single leg squats to strengthen the knee "could improve muscular performance and enhance a muscle's potential for dynamic stabilisation (of the knee)." [2]

The Single leg squat was subsequently developed from an exercise into a functional clinical test by Liebenson, a chiropractor in Los Angeles, United states of America in 2002. It was created to assist practitioners in examining the function of the lower extremity kinetic chain. [3]

The Single leg squat test is a clinical test, conducted in the position of single limb stance.[4] This position is seen in many daily functions such as walking and running, or in sports[4] such as football, rugby, hockey, gymnastics and skiing. An individual walks over 10,000 steps per day on average[5-7] and a professional football player runs over 10km per game.[8,9] Therefore the test appears to have good face validity as single leg stance is a position both healthy and sporting individuals go into repetitively and frequently. The Single leg squat test is frequently used clinically to provide a simple and convenient assessment of neuromuscular control for the Lumbo-Pelvic region.[10-12] It is assumed performance of the single leg squat reflects the movement that is likely to occur during more complex tasks such as gait. However, the potential link between Single leg squat performance and gait kinematics has only started to be investigated after 2009.[10]

The Single Leg Squat Test

Benn and colleagues' work focused on the effect of a single leg squat as a strengthening exercise for the knee. [2] Liebenson developed the single leg squat exercise into a test. He stated that when the Single leg squat is considered as a test then it may indicate many movement dysfunctions within the kinetic chain including pelvic unleveling, valgus overstrain at the knee and subtalar hyperpronation.

However Livengood was the first author to define a method for performing the Single leg squat as a test. [13]

Previously Liebenson had interpreted the test in an ordinal manner (positive or negative). Livengood was the first author to assign the test a scale. This converted it into nominal data. Table 2.

Table 1: Single Leg Squat Dysfunctions – adapted from Liebenson [3]

Sign	*Dysfunction*
Subtalar hyperpronation	Tibial Torsion
Early Heel rise	Tight soleus
Femoral torsion or Valgus overstrain	Hip or Pelvic torsion dysfunction
Trendelenburg Sign or Pelvic unleveling	Gluteus Medius insufficiency
Poor control of knee when rising up	Gluteus Maximus insufficiency
Excessive Trunk Flexion or control of knee extension on rising up	Gluteus Maximus insufficiency

Table 2: Single leg squat - Scoring Criteria for movements of closed chain limb

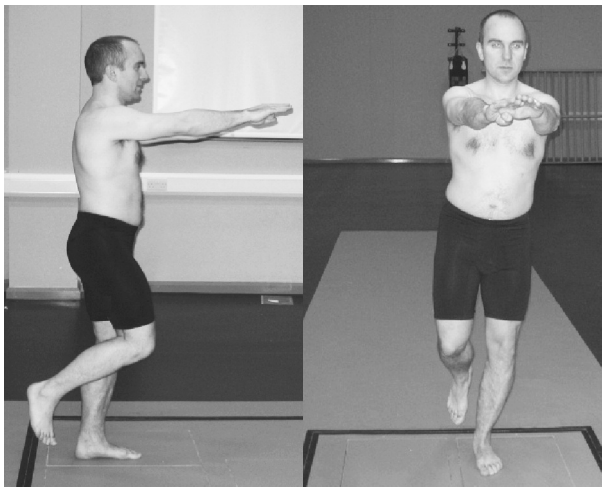
Grade	*Hip and Knee Criteria*
Excellent	Hip flexion greater than 65^0, hip abduction / adduction less than 10^0, knee valgus / varus less than 10^0
Good	Any of the above 2 criteria are met
Fair	Any 1 of the above criteria are met
Poor	None of the criteria are met or the athlete losses balance or falls

Previous Studies

From 2004 most studies of the Single leg squat test were kinematic studies. Earlier studies (2004-2007) are predominantly of patellofemoral pain syndrome patients, after 2007 more varied groups have been studied including healthy individuals,[14] OA, [15] ACL patients[16] and athletes. [11]

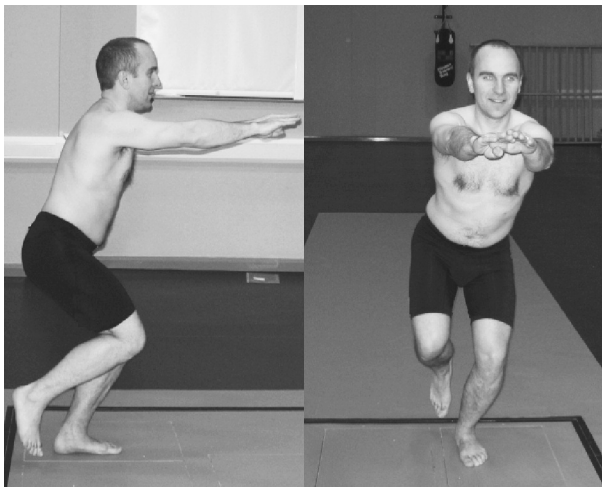
Levinger (2004) compared the calcaneal kinematics of patellofemoral pain syndrome patients and healthy individuals during the Single leg squat (n=30). 2D Data was collected using video tape, at an unstated frequency, of participants performing a Single leg squat to 45 degrees of knee flexion. The authors concluded that patellofemoral pain syndrome patients exhibited a significantly larger peak calcaneal eversion angle (p=0.02) and that this may contribute to altered kinematics proximally in the kinetic chain, at the knee and hip.[17] Levinger (2007) extended his earlier work being the first author to investigate the femoral kinematics during the Single leg squat. This study compared patellofemoral pain syndrome patients to healthy participants using a single video camera at 50Hz. The authors concluded that the femoral medial deviation in the coronal plane (hip adduction) was significantly larger for patellofemoral pain syndrome patients (p=0.019).[18] However Levinger did not use Livengood's method for performing the test. Table 3.

Figure 1
Single Leg Squat - Start /finish position



"The athlete stands on the limb being evaluated, with the other leg lifted off the ground so that the hip is flexed to approximately 45^0 and the knee to approximately 90^0. The athlete's shoulder's are forward flexed to 90^0, with the elbows in full extension and the hands clasped together in front."

Figure 2
Single Leg Squat - Squat position



"The athlete is instructed to squat down to approximately 60^0 and return to the start position in less than 6s."

Table 3: Single leg squat test- Comparison Livengood's with Levinger's method

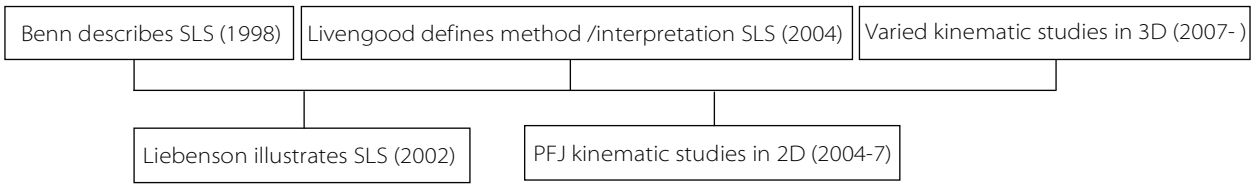
Method	*Livengood*	*Levinger*
Test Posture	Single limb stance	Single limb stance
Pelvic Position	Neutral	Unstated
Upper limb Position	Shoulders flexed to 90 degrees	Shoulders dependant
Duration	6 seconds	Unstated

A potential error was that transverse plane hip and knee movement was not controlled for. Therefore the femoral angle measured in 2 dimensions from the video may have contained errors from movement in the transverse plane. After 2007 most studies have been kinematic, laboratory based studies. Wilson (2007) also studied the Single leg squat, running and single leg jump kinematics in patellofemoral pain syndrome patients and healthy individuals (n=40). However Wilson used a 6 camera Vicon movement analysis system at 120Hz. This allowed movement analysis in all 3 planes of motion unlike Levinger who's video was confined to 2 planes of motion. The author concluded that a significantly different hip adduction movement existed between the groups ($p=0.019$) with a mean of 7.79^0 +/- 4.42^0 for the control group and 11.75^0 +/- 3.61^0 for the patellofemoral pain syndrome patients during the three activities . Femoral deviation showed no significant differences ($p=0.295$) with a mean of 2.02^0 +/- 1.11^0 for the control group and 2.54^0 +/- 1.29^0 for the patellofemoral pain syndrome patients during the three activities. Mean knee flexion also showed no significant differences ($p=0.829$) with a mean of 45.3^0 +/- 0.39^0 for the control group and 45.3^0 +/- 0.47^0 for the patellofemoral pain syndrome patients during the three activities.[19] Wilson, in common with Levinger, stated that patellofemoral pain syndrome patients demonstrated greater hip adduction however neither author used Livengood's method for performing the test. Levinger's participants were bare foot but Wilson's wore footwear, this may have influenced the kinematic data making comparison between the studies difficult.[20] McQuade (2007) investigated the effect of knee strengthening training on Single leg squat's knee kinematics and surface muscle EMG activity (n=6). However in contrast to previous work this was the first study using participants with OA. The author's describe an EMG driven musculoskeletal model to estimate joint reaction forces at the knee using an inverse dynamics approach but did not define the strengthening regime or method for performing the Single leg squat. They concluded that knee strengthening training increased the knee muscle's strength and improved the subject's balance but did not change the knee joint kinematics.[15]

Two studies in 2009-2010 compared the kinematics of gait to the Single leg squat. Alexander (2009) was the first author to investigate the hip and knee kinematics of normal, healthy, male and female subjects using a motion analysis system (Vicon, n= 11). The authors found that poor performers of the Single leg squat test walked with greater hip abduction during stance when compared to good performers of the test. They concluded that performance of the Single leg squat task appears potentially capable of providing a reflection of neuromuscular control during gait.[10] Perrot (2010) compared the Single leg squat test to dip test in recreational athletes (n = 22). The dip test is a similar test to the single leg squat but performed with one foot resting on a support that reduces dorsiflexion and balance demands. The authors concluded that participants with poor Lumbo-pelvic stability exhibited higher hip adduction of the trial leg, hip abduction of the stance leg, pelvic obliquity and trunk rotation ($p<0.01$).[11] Therefore this study agrees with Alexander (2009) that poor performance of the Single leg squat test is associated with greater hip abduction of the stance hip. However Perrot did not describe the analysis system they used. It is also unclear if the conclusions relate to both the Dip and Single leg squat test or only to dip test.

Jennison (2010) investigated the association between foot orthoses and quality of Single leg squat in patellofemoral pain syndrome patients (n=23). An assessor rated video footage of five consecutive Single leg squats rating the squat as "poor", "fair" or "good". They concluded that individuals at baseline who exhibited fair to good quality of Single leg squat using the foot orthoses are more likely to have better outcomes at 12 weeks than individuals with poor quality of single leg squat ($p<0.05$, $r=0.46$).[20] A subsequent study by Madhaven (2010) investigated the differences in neuromuscular response between participants who had an ACL reconstruction and healthy female subjects during the Single leg squat (n= 24). Data was collected of surface EMG activity, frontal (coronal) and sagittal plane centre of pressure. The authors found less background EMG activity, increased overshoot error and knee velocity whilst undergoing unexpected perturbations in the ACL reconstruction participants. Of clinical significance is that in the ACL reconstruction participants the long latency response, the reflex which may play a significant role in preventing joint stability, was enhanced. The authors suggest that this maybe a protective response that developed in this group due to surgery, rehabilitation or the severity of the injury.[16] Madhaven states that he used the Single leg squat method as described by Livengood.[13] However Madhaven allowed participants to place two fingers onto a load sensor. Whilst loads were low (under 3N) this allowed a degree of fixation

Figure 3
Development of the Single leg squat test



of the upper limb, hence closing the kinetic chain. [21] Livengood's method also has the shoulders forward flexed to 90 degrees, not dependant as Madhaven. Hence Madhaven's methodology was the same as Levinger,[18] not in strict adherence with Livengood's, and may have influenced the participant's performance of the test.

Therefore contemporary evidence has shown that the Single leg squat test has developed from an exercise into a clinical test. It is now being used clinically and within research. This research has progressed from being predominantly 2D studies using video into 3D motion analyisis studies. Figure 3.

Standardisation of the Single Leg Squat Test

The Single leg squat test is a useful clinical test.[10] It is frequently used clinically to provide a simple and convenient assessment of neuromuscular control for the Lumbo-Pelvic region.[9-11] It is assumed performance reflects that which is likely to occur during more complex tasks such as gait.[10] Standard 6 in the UK Chartered Society of Physiotherapy Core Standards document makes an explicit requirement for members to use published, standardised outcomes (tests) in clinical practice.[22,23] McDowell states that "An outcome measure should be standardised, with explicit instructions for administration."[24]

Billis (2003) and Hestboek et al (2000) found both physiotherapists and chiropractors' had different methods for performing similar clinical Lumbo-pelvic tests.[25,26] French (2000) found chiropractors interpreted the response to common, clinical Lumbo-pelvic tests differently.[27] These studies showed poor intra and inter-tester reliability.[25-27] It maybe concluded that where clinical tests have different methods or interpretation then intra and inter-tester reliability is inevitably poor. Equally to raise intra and inter-tester reliability clinical tests need to be "precise, reproducible and highly standardized."[28] Livengood's method provides such an "operational definition" [31] i.e. a clear method and interpretation. Interestingly no studies were found of orthopaedic surgeon's reliability when performing common clinical tests for the Lumbo-pelvic region.[29]

Liebenson used clinical observation to describe the Single leg squat. He illustrated the Single leg squat by drawings.[3] Livengood and DiMattia used laboratory based studies with both clinical observation and modern equipment such as high resolution video cameras and dynamometers.[13,30] They conveyed the Single leg squat by photographs and description. Both Livengood and DiMattia used experimental, same-subject crossover designs. Inter and intra-comparative group analyses were made. The landmark work of Livengood[13] has now become the standard for the test's method and interpretation. However many subsequent studies either fail to describe their method for the tests [10,11,15,20] state that they are using Livengood's method but are not [16] or use their own method. [17-19] This makes inter-study comparison difficult.

Hardcastle found that in children under four the Trendelenburg Test could not be reliably used, and over four years of age only if they could understand and fully co-operate. They also defined false negative or positive responses. [31] The Trendelenburg Test is thought to be similar to the Single leg squat[13] however, in contrast, none of the studies reviewed have defined exclusion criteria, false negative or positive responses for the Single leg squat test.

Evidence for the Single leg squat test has been confined to healthy individuals[13,30] aged 24 (+/- 4), [30] Patello-femoral,[17,18,20] post ACL repair [16] and athletic individuals. [11] There is limited evidence for subjects outside of this age group or for the athletic population.

Evidence shows the Single leg squat test to be a relatively new test. This may explain why the evidence does not come from many sources internationally or from a wide variety of orthopaedic practitioners. Evidence to date comes from American [13,17,19-23] or Australian[10,11,23] based practitioners in Physical Therapy, [2,23] Kinesiologists [13,17] and chiropractic.[3] Most studies have focused on the knee [19-24] with few studies including its relationship to pathology or dysfunction proximal or distal within the kinetic chain. [21,22]

Only one author, Livengood, has objectively defined when the Single leg squat test becomes positive. Hip flexion greater than 65^0, hip abduction / adduction greater than 10^0, knee valgus / varus greater than 10^0. [17] This study has made the Single leg squat test more objective. Presently there is no evidence if a practitioner could "eyeball" a change of hip abduction / adduction less than 10^0, knee valgus / varus less than 10^0. The author suggests that they may find it difficult clinically to identify such a small movement. All of these studies confined themselves to coronal plane motion. There is no existing data for sagittal, coronal and transverse plane pelvic motion during the Single leg squat Test.

Table 4: Single leg squat test- Summary of current studies

Author	*Method*	*Interpretation*	*Inclusion / Exclusion criteria*	*Population / Age*	*Practitioner*
Benn [2]	Descriptive	N/A	Unstated	Normal / unstated	Physical Therapy - USA
Liebenson [3]	Figure	Yes - qualitative	Unstated	Normal / unstated	Chiropractic - USA
Livengood [13]	Defined	Defined - quantitative	Unstated	Normal / unstated	Biomechanist - USA
DiMattia [30]	Livengood	Livengood	Unstated	Normal / unstated	Athletic Trainer - USA
Levinger [17]	Unstated	Unstated	Unstated	Patello-femoral pain / unstated	Unstated - USA
Levinger [18]	Unstated	Unstated	Unstated	Patello-femoral pain / unstated	Unstated - USA
Willson[19]	Own version	Unstated	Unstated	Patello-femoral pain / unstated	Physical Therapy - USA
McQuade [15]	Limited description	Unstated	Unstated	OA knee / unstated	Unstated - USA
Alexander [10]	Unstated	Unstated	Unstated	Unstated / Unstated	Unstated - Australia
Perrot [11]	Unstated	Unstated	Unstated	Athletes / unstated	Unstated - Australia
Jennison [20]	Unstated	Unstated	Unstated	Patello-femoral pain / unstated	Unstated - Australia
Madhaven [16]	Own version	Unstated	Unstated	ACL / unstated	Physical Therapy - USA

CONCLUSION

The Single leg squat Test is a relatively new clinical test. It is a modern, objective clinical test. It has evolved from the double leg squat exercise. Presently it has only been used by a few professions on limited populations. It has been given a clear method and interpretation by Livengood.[13] However a limitation of this combined evidence is that the data reported is confined to hip sagittal and coronal plane, and knee in the coronal plane. Despite human motion occurring in three planes of motion there is no data for combined sagittal, coronal and transverse plane pelvic motion during the Single leg squat test.

It is clear that further research is required into the biomechanics of the Single leg squat test and its relationship to functional anatomy. To conduct this research optimally Livengood's method and interpretation should be used. By adhering strictly to this method it is anticipated that testing would have high intra and inter tester reliability. The collection of data for sagittal, coronal and transverse plane pelvic motion during the test would fill an evidence vacuum. Future research should investigate the reliability and validity of the Single leg squat test within specific populations. This may in turn help explain the mechanisms and presentations of specific gait types.

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