

The single leg squat: when to prescribe this exercise

By **Chris Bishop,¹ Simon Brierley,² Paul Read,³ and Anthony Turner,¹**

¹London Institute of Sport, Middlesex University ²Cranleigh School ³St Mary's University, London

INTRODUCTION

The single leg squat (SLS) is an exercise that has been the subject of numerous research studies in recent years – primarily in the field of physiotherapy and sport rehabilitation, considering where the majority of literature has been published. The unilateral nature of the exercise has encouraged researchers and practitioners to identify what the key muscles are when performing this movement pattern and the factors that may be responsible for enhancing performance during this particular task. From a rehabilitation standpoint, the literature has tended to focus on the capacity of the SLS to identify issues with kinematic differences (primarily at the hip and knee),^{2, 6, 18, 23, 25} the importance of trunk strength,^{29, 30, 32} and differences in performance (again most notable at the hip and knee) between injured and non-injured populations.^{13, 14, 31} It would appear that any movement compensations that occur typically do so at the hip and knee joints.

Furthermore, the SLS has been commonly used as a tool in movement screening protocols, perhaps most notably by the National Academy of Sports Medicine (NASM),^{7, 8} who advocate its use alongside that of the overhead squat as a method of providing practitioners with an overall indication of movement quality. Therefore, the applicability of the SLS would appear to branch across more than one remit within the strength and conditioning (S&C) coach's role, which justifies having a deeper understanding of the factors affecting this exercise. With this in mind, the purpose of this article is first to outline the key muscles that would appear to be recruited during this exercise (as acknowledged in the literature), and secondly, to discuss critically which joints are affected when athletes perform this exercise, highlighting when and if we should prescribe this exercise to our athletes.

Muscle activation

Numerous studies have investigated activation patterns during the SLS, allowing coaches to understand which muscles are being targeted by this exercise. However, methods are seldom the same and therefore it is important to understand how the results relate to

the specific methods employed in each study. Results are typically reported as a percentage of maximal voluntary isometric contraction (MVIC) and all results reported in this review will follow that assumption unless stated otherwise.

DiStefano et al¹¹ examined muscle activation of the gluteus maximus

Table 1. Normalised gluteus maximus and medius mean and standard deviation signal amplitude expressed as a percentage of MVIC (adapted from DiStefano et al)¹¹

EXERCISE	GLUTE MAXIMUS	EXERCISE	GLUTE MEDIUS
Single leg squat	59 ± 27	Side-lying hip abduction	81 ± 42
Single leg deadlift	59 ± 28	Single leg squat	64 ± 24
Transverse lunge	49 ± 20	Lateral band walk	61 ± 34
Forward lunge	44 ± 23	Single leg deadlift	58 ± 25
Sideways lunge	41 ± 20	Sideways hop	57 ± 35
Side-lying hip abduction	39 ± 18	Transverse hop	48 ± 25
Sideways hop	30 ± 19	Transverse lunge	48 ± 21
Clam (60° hip flexion)	39 ± 34	Forward hop	45 ± 21
Transverse hop	35 ± 16	Forward lunge	42 ± 21
Forward hop	35 ± 22	Clam (30° hip flexion)	40 ± 38
Clam (30° hip flexion)	34 ± 27	Sideways lunge	39 ± 19
Lateral band walk	27 ± 16	Clam (60° hip flexion)	38 ± 29

and medius during 12 commonly used bodyweight exercises within the fields of rehabilitation and S&C in 21 healthy subjects. Muscle activation results can be seen in Table 1.

Although S&C coaches will always have an arsenal of exercises at their disposal for programme design, if one exercise had to be picked to target both gluteal muscles, the single leg squat would appear to be the logical choice due to its capacity to recruit the gluteus maximus more than any other tested exercise and more than all other exercises bar one for gluteus medius activation. It is not surprising that the SLS did not activate the gluteus medius more than the side-lying hip abduction as this is the position used for testing maximal voluntary isometric contractions, thus contracting the glute medius to its full capacity (hip abduction).^{7, 8} However, for an exercise that is supposed to be performed primarily in the sagittal plane of motion, its ability to recruit a muscle that traditionally functions in the frontal plane demonstrates its high level of functionality.

These results are supported by the findings of Boudreau et al,⁵ who investigated the electromyography (EMG) during the SLS, lunge and step-up-and-over exercises. The SLS demonstrated a significantly higher activation ($p \leq 0.017$) in the rectus femoris (26.7%), gluteus maximus (35.2%) and gluteus medius (30.1%). Although EMG values were considerably lower than DiStefano's results, the trend of muscle activation followed the same pattern when compared across the tested exercises.

Further support is offered by Zeller et al,³⁶ who studied the differences in the EMG of six lower body muscles between male ($n = 9$) and female ($n = 9$) college athletes while they carried out five SLSs on their dominant leg. Gluteus maximus activation was comparable with the results seen in DiStefano's research for the male subjects (63%) and even higher for females (81%), but the highest activation was seen in the vastus lateralis for both males and females who reported 81 and 116% respectively.³⁶ Interestingly, although not statistically significant between genders ($p = 0.14$), gluteus medius activation was considerably lower for females (77 vs 41%). Furthermore, the authors noted a combined unwanted movement of knee valgus and hip adduction in the majority of the female athletes' technique, which may explain the lower levels of gluteus medius activation. Consequently, the reduced level of gluteus medius activity may have resulted in higher levels of quadriceps activation in the female population, which may explain the results for the vastus lateralis. Finally, gastrocnemius activity in the female subjects was 2.5 times greater than that of the males, which when combined with the increased quadriceps activation would indicate that the females in this study may have used a more 'knee dominant' movement strategy to perform the SLS. Using a 'hip hinge' strategy has been previously reported in optimal squatting mechanics;²¹ coaches should therefore always be aware of optimal movement mechanics when viewing their athletes' technique.

Muscle activation has also been reported for subjects displaying poor movement

'if one exercise had to be picked to target both gluteal muscles, the single leg squat would appear to be the logical choice'

mechanics and injury symptoms. Mauntel et al¹⁷ also investigated muscle activation in the glute complex, hamstring, quadriceps, adductors and gastrocnemius during the SLS for 20 subjects (10 male; 10 female) that exhibited knee valgus. Subjects were not injured, but merely portrayed movement compensation when asked to perform the exercise and were required to squat to a box so that when the gluteus maximus grazed the surface, the knee joint measured 60° flexion. Muscle activation was once again highest in the quadriceps, namely the vastus lateralis at 75.2%; however, there were notably lower results reported for the gluteus maximus (17.1%) and medius (32.9%) than compared to DiStefano and Zeller's research.¹⁷

Although caution should be taken comparing results across different samples (as no one sample is ever likely to portray identical results to another), this trend in reduced gluteus muscle activation has also been noted in subjects with knee injury symptoms.

Nakagawa et al²² investigated the gluteus maximus and medius activation levels in male and female subjects with patellofemoral pain syndrome (PFPS). Male and female subjects (20 per group) were familiarised with the SLS technique and asked to perform three five-second repetitions. Gluteus maximus and medius activation was considerably lower in both groups when compared with the data for healthy populations. Females demonstrated slightly higher activation levels in both muscles, with the gluteus maximus results reported as 24.1 and 20.6% and gluteus medius activation reported at 23.7 and 17.9%.²² In addition, the authors reported multiple movement compensations which included contralateral pelvic drops, hip adduction and hip internal rotation. Additional muscles were not tested during the methodology; however, it is logical to assume that these movement compensations may have limited the amount of glute activation during testing protocols. Finally, although circumstantial, these movement compensations could have been a strategy that subjects adopted in an attempt to cope with any discomfort experienced throughout the testing procedures.

In conclusion, it would appear that higher levels of muscle activation are apparent when subjects demonstrate optimal movement mechanics, most notably when no knee valgus or hip adduction occurs. It is also evident that for those studies that tested it, quadriceps activation would appear to

be higher than the glute complex; a notion that seems to exist whether technique is optimal or not. However, this particular interpretation should be made with caution as the authors were only able to find one study that reported quadriceps activation in the testing protocols of subjects specifically displaying movement compensations.¹⁷ Finally, it would appear that some good research has been undertaken comparing the muscle activation of the SLS against comparable exercises, but perhaps more research is needed to provide direct comparisons between injured and non-injured athletic populations, which may allow researchers and practitioners to undertake a more in-depth analysis of performance on this exercise, given that it seems to have become a commonly used screening tool.^{7, 8, 19}

Movement compensations and the importance of hip strength

We know that the glute complex and quadriceps typically activate the most during the SLS exercise, whether movement mechanics are optimal or not. However, it would appear that movement compensations are not uncommon during this task,^{6,13,14,16,22}

'gluteus medius, hamstrings and quadriceps all had a significant role to play in controlling frontal plane knee movement during the SLS'



and therefore understanding what compensations are typically associated with this movement pattern will allow coaches to better interpret what they see when their athletes are performing this exercise in the weight room. The rationale for needing this information in the first instance is that the SLS can and has been used for movement screening protocols,^{7,8} and may have implications for coaching practice and programme design.

Claiborne et al⁶ researched whether there was a relationship between hip/knee strength and knee valgus while performing a SLS to approximately 60° knee flexion in 30 healthy adults (15 men, 15 women). Frontal plane knee movement was analysed using 3-D motion analysis and isokinetic hip abduction/adduction, flexion/extension and knee flexion/extension were also tested. Results indicated that hip abduction ($r^2 = 0.13$), knee flexion ($r^2 = 0.18$) and knee extension ($r^2 = 0.14$) were significant predictors of knee valgus movement. Results also showed significant negative correlations between knee valgus and hip abduction ($r = -0.37$), knee flexion ($r = -0.43$) and knee extension ($r = -0.37$) peak torque.⁶

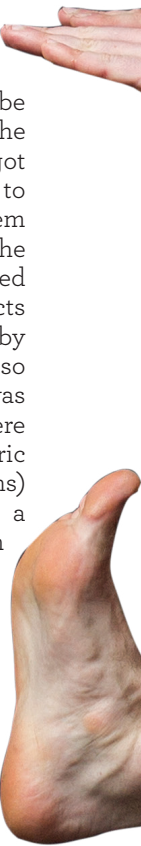
The key finding from Claiborne's research was that the gluteus medius, hamstrings and quadriceps all had a significant role to play in controlling frontal plane knee movement during the SLS. This is not surprising when we consider that quadriceps and gluteal activation are typically the highest during this task. However, hamstring contribution was not overly noted when discussing muscle activation in the SLS; most likely because of the muscle group's bi-articular structure. This means that during the descent of a squat pattern, the hamstrings will lengthen at the hip and shorten at the knee, and vice versa during the ascent. Consequently, their relative contribution to squatting motion may not be as high as the glutes and quadriceps. In contrast, Clairborne's evidence provides us with a supporting rationale not to neglect the hamstrings when aiming to strengthen muscle groups that can positively affect knee valgus motion. With that in mind, exercises such as Romanian deadlifts and Nordic curls are best known for targeting the hamstring group and provide simultaneous flexibility and strength due to the nature of how they are performed. However, with the SLS being performed unilaterally, it would seem prudent that the single leg Romanian deadlift be suggested as an exercise to both target the hamstrings and retain the specificity of working on one leg.

Willy and Davis³³ investigated whether a six-week hip strengthening programme could positively enhance running and SLS performance in 20 healthy, female runners. The group was divided into an experimental and control group (n = 10 per group), with the experimental group performing exercises that targeted the hip abductors and external rotators three times a week. It should be noted that the SLS was incorporated into the programme design, with a focus on making it progressively harder for the last three weeks. This was done by offering subjects a support the first week they attempted it, then removing that support the following week (as per the requirement during the test), and then finishing with subjects performing the task with a resistance band, so as to increase the challenge of resisting frontal plane knee movement.³³ Hip abduction and external rotation strength significantly improved in the experimental group (p < 0.005) and hip adduction, hip internal rotation and contralateral pelvic drop all significantly reduced (p = 0.006, p = 0.006 and p = 0.02 respectively) during the SLS, justifying the incorporation of a specific glute strengthening programme for these runners. Interestingly, however, the authors reported that there was no significant improvement in running mechanics.

The combination of these results could be explained by three plausible reasons. The first is that the experimental group just got stronger (as the results reported) due to the designed intervention allowing them to perform the SLS better at the end of the study. Secondly, the intervention included SLS 'practice' and challenged the subjects beyond what was required for re-testing (by integrating the use of a resistance band), so that when the bodyweight movement was required post-intervention, subjects were able to withstand higher levels of eccentric force (as indicated by the compensations) than they could before. Thirdly, from a screening perspective, there is a notion that subjects may execute slower movement patterns adequately, but when higher amounts of velocity are added to the equation, movements can be detrimentally affected.^{3,4,12} In this instance, running represents a much more dynamic movement pattern than the SLS, and the runners may not have been able to control the un-wanted mechanics due to the higher forces experienced in this activity, not to mention the specificity of running itself.

Finally, DiMattia et al¹⁰ used 50 healthy

'hamstrings will lengthen at the hip and shorten at the knee, and vice versa during the ascent'



subjects to perform both the SLS and an isometric hip abduction exercise. Participants were placed in a side-lying position, with a strap and hand-held dynamometer located over the lateral femoral condyle for the hip abduction exercise; and they were asked to maximally abduct the hip for four seconds. For the SLS, subjects were required to perform the exercise until the knee reached a 60° angle (previously measured by a goniometer and standardised by a box beneath them) and complete a maximum of five repetitions. Results demonstrated a weak positive correlation ($r = 0.21$) between hip abduction strength (from the isometric test) and hip adduction angles (seen in the SLS).¹⁰ The hypothesis was that those subjects who demonstrated high levels of hip abduction strength would exhibit lower amounts of hip adduction, and although a correlation was present, it was not strong. The authors proposed that the SLS may have relied on additional muscles not tested in their procedures. This would appear to be a logical assumption, based on the EMG data in the first section of this article and the importance of the hamstrings and quadriceps as identified by Claiborne et al.⁶

In contrast, the study by Mauntel et al.¹⁸ provided evidence against the argument that hip strength is a predictor of SLS performance, by comparing 3-D hip and knee angles in subjects who displayed medial knee displacement ($n = 20$) and those who did not ($n = 20$; acting as the control group). Results indicated a significant difference for knee valgus between groups, with the control group showing a mean valgus angle of 6.08° and the medial knee displacement group displaying over double the unwanted movement as represented by a mean valgus angle of 12.86°,¹⁸ corresponding to a large effect size of 1.23.²⁷ Previously reported joint movements of interest such as knee flexion, hip adduction and hip internal rotation were also measured, but no significant differences were found in this instance.



The authors suggested that knee valgus was a significant factor in contributing towards medial knee displacement, but other joint movements such as hip strength were not. In addition, it was also suggested that more research was needed on whether the SLS could act as a predictor for non-contact injury and that other assessments such as the Landing Error Scoring System (LESS) may be considered alongside the SLS,¹⁸ due to its capacity to distinguish between subjects that have and have not had previous ACL injury.²⁴

Although the results in this study do not support the importance of hip strength during SLS performance, both the isolated and integrated function of the glute complex should not be forgotten. It has been acknowledged that the gluteus maximus both extends and externally rotates the hip joint, whereas the gluteus medius is primarily responsible for hip abduction.⁷ In a more integrated environment, the glutes are responsible for dynamically stabilising both the lumbo-pelvic hip complex and the knee joint,^{7,8} meaning that because they are both hip abductors and external rotators, they are said to play a pivotal role in keeping the knee 'neutral' during functional tasks such as squatting. Therefore, although the results in Mauntel's research do not support the importance of hip strength in this exercise, the majority of research done in this area would appear to favour the opposing view.^{6, 7, 8, 10, 33}

ATHLETES WITH KNEE INJURIES

Up until this point, this section has focused on 'healthy subjects' who have exhibited no symptoms of injury; however, there is some worthwhile research that S&C coaches should be aware of, particularly in populations suffering with knee injuries, as this may influence our 'return to training' strategies in the weight room.

Herrington¹³ reported knee valgus angles during the SLS in 42 female subjects, 12 of who were experiencing PFPS; the other 30 represented the control group. Frontal plane projection angle (knee valgus) was measured using a 2-D video camera operating at 50Hz, positioned at the height of the subject's knee. There was a significant difference ($p < 0.01$) between groups with mean valgus angles of $16.8 \pm 5.4^\circ$ and $8.4 \pm 5.1^\circ$ for the PFPS and control groups respectively. An almost identical study design was used by Levinger et al,¹⁴ who used 13 healthy female subjects and 12 females with PFPS. A video camera (again operating at 50Hz) was used to identify femoral frontal angle (when observed this looks like knee valgus), which was determined by measuring the angle between the lines of the anterior superior iliac spine to the midline of the femoral condyles and from the second toe to the midline of the malleoli.¹⁴ The PFPS group displayed a mean femoral frontal angle of $11.75 \pm 3.61^\circ$ and the control group reported a mean angle of $7.79 \pm 4.22^\circ$, significant at $p = 0.019$. Further to this, 46.2% of the PFPS



group reported mild discomfort during the assessment procedures (with no reports in the control group). It was suggested that the increased levels of medial deviation at the knee may have been down to reduced muscle activation at the hip; this is a very plausible explanation when weakness in the gluteus medius has been shown to be an underlying reason for medial displacement at this joint.^{1, 16, 26}

Lastly, Willy et al³⁴ investigated how mechanics differed during the SLS between male and female runners with (n = 18) and without (n = 18) PFPS. Variables such as knee adduction, hip adduction, hip internal rotation and contralateral pelvic drop were all measured (in degrees) using 3-D motion analysis. Knee adduction (or valgus) was the only significant (p < 0.05) variable differentiating the groups during the SLS test, with the PFPS group (males only) showing knee adduction angles of $6.0 \pm 4.6^\circ$ and the control group only deviating medially by $2.4 \pm 4.3^\circ$.³⁴ Interestingly, however, despite the difference between the two groups, the amount of knee adduction was very consistent for males with and without PFPS, meaning that the SLS may prove to be a useful screening tool for those with or without knee injuries, a conflicting view from that of DiMattia et al.¹⁰

The evidence presented in this section has demonstrated that the SLS has the capacity to identify multiple movement compensations: most notably knee valgus, hip adduction and alterations to pelvic alignment such as contralateral pelvic drops. All the literature in this section bar that of Mauntel et al¹⁸ would suggest that glute strength plays a pivotal role in optimising performance during the SLS task. Further, the role of the hamstrings must not be underestimated when it comes to resisting medial rotation at the knee.⁶ Finally, if athletes are injured or showing symptoms (particularly at the knee joint), it is probable that unwanted mechanics might be more evident in their movement patterns; therefore, some practical guidelines on how coaches can enhance performance during the SLS would be useful.

Practical application

From the evidence presented, there are some contrasting results, which provide the practitioner with challenges as to 'how best to utilise this exercise', should it be deemed appropriate for the athlete. The SLS's ability to highlight movement



compensations in a unilateral environment would appear to be insightful; thus it would seem prudent to suggest that its use could be served best as part of a movement screening protocol, allowing for continuous monitoring of improvements during this task. The advanced nature of the exercise may in itself provide a rationale for using it within a screening battery, as suggested by the NASM,^{7, 8} highlighting whether an athlete's quality of movement even warrants its consideration in programme design. However, it would also be useful to know when we should consider using this exercise during programme prescription and when alternatives may be a more appropriate option.

As previously discussed, the glute complex appears to play a crucial role in determining SLS performance. Research from Willy and Davis³³ indicates that simply practising the exercise can promote desirable improvements in performance, but that its inclusion into programme design is at the discretion of the coach. Having said that, it should be reiterated that as per the EMG research, this exercise (from a unilateral standpoint) would appear to be one of the most effective at recruiting the gluteus maximus and medius muscles.¹¹ Therefore, if it is deemed that unilateral exercises will complement an athlete's physical development and the athlete's form when performing this task does not exhibit unwanted movement mechanics, then the SLS may prove to be a very effective exercise selection.

From an opposing perspective, the heightened nature of resisting frontal plane forces that accompanies unilateral exercises²⁰ may provide athletes with difficulties in perfecting this exercise, particularly those with injury symptoms. Macadam et al¹⁵ suggest that as exercise complexity increases so too does the requirement for gluteal activation, but if

'the SLS would appear to be one of the most effective at recruiting the gluteus maximus and medius muscles'

technique is deemed 'too poor' to warrant prescribing it in the first instance (which will most likely be characterised by excessive knee valgus), then alternatives such as step-ups and lunge variations may allow coaches to target forms of unilateral training without as high a risk of compensations occurring, as noted by Boudreau et al.⁵

It is therefore the suggestion of the authors that the SLS be used as a method for screening movement quality in a unilateral environment and, for those athletes who do not exhibit unwanted movement mechanics such as knee valgus (which would be determined from the screen), that SLS should be included as part of an athlete's overall physical development if the coach deems it appropriate. Additionally, a further strategy may be to regulate how deep the athlete is instructed to squat, depending on form. A bench or box could be used (as per the methods of DiMattia¹⁰) as a 'target' to ensure that shallow depths are mastered without any aforementioned compensations and gradually lowered to increase the required neuromuscular control as the athlete gets stronger. This may also prove to be a useful variation for athletes demonstrating injury symptoms, by allowing them to both maintain alignment and reduce any stress on the affected joints.

There is also the issue of motor control in relation to enhancing SLS performance. It is advisable to establish the required motor pattern for a given task, otherwise the musculoskeletal system is likely to afford all and any available options in order to self-stabilise and maintain equilibrium. This is as much a 'coachable' as it is a 'trainable' quality - where the S&C professional is required to have an armoury of solutions to help the favourable movement pattern emerge. According to existing literature, the coach is advised to base their coaching strategies around the intention-action model and intrinsic knowledge of results.³⁵

An in depth explanation of these models lies outside the scope of this article, but these outcome-based approaches have been found to be a useful method for enhanced motor learning.²⁸ By way of example, the coach may constrain the athlete to a more hip-dominant pattern during the SLS task by placing a barrier in front of their shins, thus limiting forward motion of the shank. Alternatively, the athlete could be encouraged to resist hip adduction by actually imposing a resistance medially which should encourage the brain to find a counter-strategy by driving the knees out.

These are just two examples that the authors of this article have found to be effective in practice, but it is emphasised that a variety of drills are likely to elicit optimal learning and retention.

The importance of activating the trunk musculature has also been noted in the literature and should not be overlooked. Stickler et al³⁰ and Willson et al³² investigated the association between selective measures of core strength and SLS performance. Stickler et al³⁰ found a moderate correlation ($r = 0.426$; $p = 0.006$) between the side lying plank (measured by peak isometric force) and SLS performance, suggesting that the internal oblique muscles may have a role to play in enhancing performance. Similarly, Willson et al³² identified a significant correlation between the trunk extensors ($r = 0.26$, $p = 0.05$) and trunk lateral flexors ($r = 0.27$, $p = 0.04$) and reduced amounts of frontal plane projection angle at the knee joint. This time the subjects included 46 athletes from NCAA division 1 basketball, football and volleyball, with results suggesting that those athletes with stronger erector spinae and quadratus lumborum muscles were better able to resist the unwanted motion of knee valgus. Finally, Shirey et al²⁹ compared the SLS under two conditions: one where the trunk muscles were 'intentionally engaged' and the other (the control group) which did not engage them. The group which intentionally activated their trunk muscles prior to the test demonstrated significantly less frontal plane hip displacement ($p = 0.01$) and a significantly deeper squat ($p = 0.009$), suggesting that bracing the abdominal complex can have a positive effect on reducing un-wanted motion at the hip and knee joints.

Therefore, strategies that aim to activate the intrinsic core stabilising muscles and create stiffness through the trunk may provide athletes with additional stability around their centre of mass when in an unstable environment. Exercises such as planks, rollouts and cable rotations will target the abdominal and oblique muscle groups, and cueing the athlete to brace or engage the abdominal complex prior to movement²⁹ may also enhance SLS performance indirectly.

Conclusion

Understanding movement compensations during the SLS is critical when aiming to optimise performance during this task. Glute

'understanding movement compensations during the SLS is critical when aiming to optimise performance during this task'

and quadriceps strength have been identified in EMG studies as being the primary muscle groups responsible, especially when squatting to a level that exhibits 60° knee flexion. However, compensations such as knee valgus, hip adduction and contralateral pelvic drops would appear to be common, especially in those who are experiencing injury symptoms.

Therefore, using the SLS as a movement screen initially may allow us as coaches to determine whether this exercise is suitable for athletes prior to any further attempts. If it is deemed too advanced, then alternative unilateral options may allow for training quality to be maintained while working towards developing the strength/stability characteristics needed to perform the SLS optimally.

As a final thought, the true unilateral nature of the SLS is perhaps one of the reasons why the glute complex may be activated so well (particularly in healthy subjects) and it should therefore be considered as an exercise at which coaches aim to get their athletes competent. Not all coaches will have access to methods that employ EMG readings; therefore, if athletes are able to perform this exercise with neutrally aligned hips and without knee valgus, then it could be considered that the glute complex is working sufficiently to stabilise the body in this unstable environment.

AUTHORS' BIOS



CHRIS BISHOP,

MSC, PGCHE, ASCC

Chris is a lecturer in strength and conditioning at the London Sport Institute, Middlesex University

and consultant to a number of national level athletes in swimming. Chris is also on the review panel for the UKSCA's newly formed Coaching Resources project.



PAUL READ,

MSC, ASCC, CSCS

Paul is a senior lecturer in strength and conditioning at St Mary's University, London. He is also an

Accredited S&C coach, consulting with professional MMA fighters and international combat athletes in a range of disciplines.



SIMON BREARLEY,

MSC, ASCC

Simon is currently the lead S&C coach at Cranleigh School, where he is responsible for the physical

development of elite junior athletes across a multitude of sports. He is presently contracted by England Golf as a regional S&C coach to both the girls and boys u16 squads and the u18 AASE squad within the South of England.



ANTHONY TURNER,

PHD, MSC, ASCC, CSCS*^D

Anthony is the director of postgraduate programmes at the London Sport Institute, Middlesex University,

where he is also the programme leader for the MSc in strength and conditioning. He is also a consultant to Queens Park Rangers Football Club and Saracens Rugby Club. Anthony was awarded the 2015 Strength and Conditioning Coach of the Year Award for Education and Research.

Appendix. The appendix provides a description of how some of the more uncommon exercises are performed, with accompanying references for further clarification.

EXERCISE	DESCRIPTION OF EXERCISE	REFERENCE
Rear foot elevated split squat (RFESS)	Rear foot is positioned elevated behind on a 12" platform to provide support while standard squat technique is performed by the front leg	McCurdy et al ²⁰
Clam	Athlete lies on their side with hips and knees flexed with one leg on top of the other. With feet remaining in position, athlete pulls the top knee away from underlying leg by abducting the hip	DiStefano et al ¹¹
Lateral band walk	A mini-band is positioned just above the knees, mid-shin or ankles (resistance is greater the lower it is) and athlete is asked to position themselves slightly flexed at the hips, knees and ankles. Athlete steps sideways against the resistance of the band retaining flexion at hips, knees and ankles	DiStefano et al ¹¹
Nordic curls	Athlete starts upright on their knees with knee joint flexed to 90° and coach holding ankles stationary behind them. Athlete attempts to hinge forward from the knee joint (remaining neutral at the hips) and lowers themselves as far as possible before returning to start position without breaking form at the hips or spine. NB: this is traditionally thought of as an advanced exercise	Comfort et al ⁹

References

- Beckman, M, Craig, R, & Lehman, R C. Rehabilitation of patellofemoral dysfunction in the athlete. *Clinics in Sports Medicine*, 8: 841-860. 1989.
- Beutler, A I, Cooper, L W, Kirkendall, D T & Garrett, W E. Electromyographic analysis of single-leg closed chain exercises: Implications for rehabilitation after anterior cruciate ligament reconstruction. *Journal of Athletic Training*, 37(1): 13-18. 2002.
- Bishop, C, Read, P, Walker, S, & Turner, A. Assessing movement using a variety of screening tests. *Professional Strength & Conditioning*, 37: 17-26. 2015.
- Bishop, C, Villiere, A & Turner, A. Addressing movement patterns by using the overhead squat. *Professional Strength and Conditioning*. In Press.
- Boudreau, S N, Dwyer, M K, Mattacola, C G, Lattermann, C, Uhl, T L & McKeon, J M. Hip muscle activation during the lunge, single-leg squat and step-up-and-over exercises. *Journal of Sport Rehabilitation*, 18: 91-103. 2009.
- Claiborne, T L, Armstrong, C W, Gandhi, V & Pincivero, D M. Relationship between hip and knee strength and knee valgus during a single leg squat. *Journal of Applied Biomechanics*, 22: 41-50. 2006.
- Clark, M A & Lucett, S C. *NASM Essentials of Corrective Exercise Training*. Lippincott Williams & Wilkins, Third Edition. 2010.
- Clark, M A, Lucett, S C & Sutton, B G. *NASM Essentials of Personal Fitness Training*, Lippincott Williams & Wilkins, Fourth Edition. 2012.
- Comfort, P, Regan, A, Herrington, L, Thomas, C, McMahon, J & Jones, P. Ankle position during the Nordic curl does not affect muscle activity of the biceps femoris and medial gastrocnemius. *Journal of Sport Rehabilitation*, DOI: <http://dx.doi.org/10.1123/jsr.2015-0130>.
- DiMattia, M A, Livengood, A L, Uhl, T L, Mattacola, C G & Malone, T R. What are the validity of the single-leg-squat test and its relationship to hip-abduction strength? *Journal of Sport Rehabilitation*, 14: 108-123. 2005.
- DiStefano, L J, Blackburn, J T, Marshall, S W & Padua, D A. Gluteal muscle activation during common therapeutic exercises. *Journal of Orthopaedic and Sports Physical Therapy*, 39(7): 532-540. 2009.
- Frost, D M, Beach, T A C, Callaghan, J P, & McGill, S M. The influence of load and speed on individuals' movement behaviour. *Journal of Strength and Conditioning Research*, 29(9): 2417-2425. 2015.
- Herrington, L. Knee valgus angle during single leg squat and landing in patellofemoral pain patients and controls. *The Knee*, 21: 514-517. 2014.
- Levinger, P, Gilleard, W & Coleman, C. Femoral medial deviation angle during a one-leg squat test in individuals with patellofemoral pain syndrome. *Physical Therapy in Sport*, 8: 163-168. 2007.
- Macadam, P, Cronin, J & Contreras, B. An examination of the gluteal muscle activity associated with dynamic hip abduction and hip external rotation exercise: A systematic review. *International Journal of Sports Physical Therapy*, 10: 573-591. 2015.
- Mascal, C L, Landel, R, & Powers, C M. Management of patellofemoral pain targeting hip, pelvis and trunk muscle function: 2 case reports. *Journal of Orthopaedic and Sports Physical Therapy*, 33: 647-659. 2003.
- Mauntel, T C, Begalle, R L, Cram, T R, Frank, B S, Hirth, C J, Blackburn T & Padua, D A. The effects of lower extremity muscle activation and passive range of motion on single leg squat performance. *Journal of Strength and Conditioning Research*, 27(7): 1813-1823. 2013.
- Mauntel, T C, Frank, B S, Begalle, R L, Blackburn, J T, & Padua, D A. Kinematic differences between those with and without medial knee displacement during a single leg squat. *Journal of Applied Biomechanics*, 30: 707-712. 2014.
- McCunn, R, Aus Der Funten, K, Fullagar, H H K, McKeown, I & Meyer, T. Reliability and association with injury of movement screens: A critical review. *Sports Medicine*, DOI 10.1007/s40279-015-0453-1.
- McCurdy K, O'Kelley E, Kutz M, Langford G, Ernest J, & Torres M. Comparison of lower extremity EMG between the 2-leg squat and modified single-leg squat in female athletes. *Journal of Sport Rehabilitation*, 19: 57-70. 2010.
- Myer, G D, Kushner, A M, Brent, J L, Schoenfeld, B J, Hugentobler, J, Lloyd, R S, Vermeil, A, Chu, D A, Harbin, J, & McGill, S M. The back squat: A proposed assessment of functional deficits and technical factors that limit performance. *Strength and Conditioning Journal*, 36: 4-27. 2014.
- Nakagawa, T H, Moriya, E T U, Maciel, C D & Serrao, F V. Trunk, pelvis, hip, and knee kinematics, hip strength, and gluteal muscle activation during a single-leg squat in males and females with and without patellofemoral pain syndrome. *Journal of Orthopaedic and Sports Physical Therapy*, 42(6): 491-501. 2012.
- Noehren, B, Barrance, P J, Pohl, M P & Davis, I S. A comparison of tibiofemoral and patellofemoral alignment during a neutral and valgus single leg squat: An MRI study. *The Knee*, 19: 380-386. 2012.
- Padua, D A, Marshall, S W, Boling, M C, Thigpen, C A, Garrett, W E, & Beutler, A I. The Landing Error Scoring System (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: The Jump-ACL study. *American Journal of Sports Medicine*, 37: 1996-2002. 2009.
- Pantano, K J, White, S C, Gilchrist, L A & Leddy J. Differences in peak knee valgus angles between individuals with high and low Q-angles during a single limb squat. *Clinical Biomechanics*, 20: 966-972. 2005.
- Powers, C M. The influence of altered lower extremity kinematics on patellofemoral joint dysfunction: A theoretical perspective. *Journal of Orthopaedic and Sports Physical Therapy*, 33: 639-646. 2003.
- Rhea, M R. Determining the magnitude of treatment effects in strength training research through the use of effect size. *Journal of Strength and Conditioning Research*, 18(4): 918-920. 2004.
- Schmidt, R A, Lange, C & Young, D E. Optimizing summary knowledge of results for skill learning. *Human Movement Science*, 9: 325-348. 1990.
- Shirey, M, Hurlbutt, M, Johansen, N, King, G W, Wilkinson, S G & Hoover D L. The influence of core muscular engagement on hip and knee kinematics in women during a single leg squat. *International Journal of Sports Physical Therapy*, 7(1): 1-12. 2012.
- Stickler, L, Finley, M & Gulgin, H. Relationship between hip and core strength and frontal plane alignment during a single leg squat. *Physical Therapy in Sport*, 16: 66-71. 2015.
- Trulsson, A, Miller, M, Hansson, G-A, Gummesson, C & Garwicz, M. Altered movement patterns and muscular activity during single and double leg squats in individuals with anterior cruciate ligament injury. *BMC Musculoskeletal Disorders*, 16:28. 2015. DOI 10.1186/s12891-015-0472-y.
- Willson, J D, Ireland, M L & Davis, I. Core strength and lower extremity alignment during single leg squats. *Medicine and Science in Sports and Exercise*, 945-952. 2006. DOI: 10.1249/01.mss.0000218140.05074.fa.
- Willy, R W & Davis, I S. The effect of a hip-strengthening program on mechanics during running and during a single-leg squat. *Journal of Orthopaedic and Sports Physical Therapy*, 41(9): 625-632. 2011.
- Willy, R W, Manal, K T, Witvrouw, E E & Davis, I S. Are mechanics different between male and female runners with patellofemoral pain? *Medicine and Science in Sports and Exercise*, 2165-2171. 2012. DOI: 10.1249/MSS.0b013e3182629215.
- Wulf, G & Prinz, W. Directing attention to movement effects enhances learning: A review. *Psychonomic Bulletin & Review*, 8(4): 648-660. 2001.
- Zeller, B L, McCrory, J L, Kibler, B & Uhl, T L. Differences in kinematics and electromyographic activity between men and women during the single-legged squat. *American Journal of Sports Medicine*, 31(3): 449-456. 2003.