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DIAGNOSTIC METHODS: Mentored Research: Narrative Review

Assessment of quality of movement during a lateral step-down test: Narrative review

Rômulo Lemos e Silva [a, b], Yago Tavares Pinheiro [a], Caio Alano de Almeida Lins [a], Rodrigo Ribeiro de Oliveira [b, c], Rodrigo Scattone Silva [a, b, *]

[a] Postgraduate Program in Rehabilitation Sciences, Faculty of Health Sciences of Trairi, Federal University of Rio Grande do Norte, Santa Cruz, Brazil
[b] Tendon Research Group–Brazil, Fortaleza, Brazil
[c] Department of Physical Therapy, Federal University of Ceará, Fortaleza, Brazil

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ABSTRACT

Introduction: Altered lower limb movement patterns during weight-bearing activities have been described as risk factors for several injuries. The lateral step-down test (LSD) was developed to be a simple, clinician-friendly tool to facilitate the assessment of lower extremity quality of movement during a functional activity. However, there is still conflicting information across the literature regarding how the LSD should be performed.
Objective: To critically review the literature regarding the assessment of quality of movement using the LSD and to provide an overview of how this test has been used, describing confounding factors and factors associated with altered movement patterns.
Methods: A literature review was conducted in PubMed/MEDLINE, COCHRANE, PEDro, SciELO and LILACS databases, by two independent reviewers.
Results: Sixteen articles met the inclusion criteria. One was a prospective cohort study to identify risk factors for injuries in military recruits. The fifteen remaining were cross-sectional studies involving healthy military recruits, physically active individuals, athletes and/or sedentary subjects, as well as participants with knee and ankle disorders. Worst quality of movement during the LSD has been associated with deficits in hip external rotation and knee extension strength as well as in ankle dorsiflexion range of motion. The reliability of the LSD has been reported to be moderate ($\kappa = 0.59–0.81$).
Conclusions: The LSD has adequate reliability and is a simple tool that can be used to quantify lower extremity quality of movement. Future studies should include standardized methods for application, scoring and interpretation of the test, so that confounding factors can be minimized.

1. Introduction

Altered movement patterns in the lower limbs during closed kinetic chain activities have been described in the literature as possible risk factors for several knee joint injuries, such as patellofemoral pain (Boling et al., 2009) (Noehren et al., 2013), anterior cruciate ligament (ACL) rupture (Hewett et al., 2005) and iliotibial band syndrome (Noehren et al., 2007). In this context, the assessment of the quality of movement during functional activities seems to be important for a better understanding of lower limb biomechanics and their relationship with injuries.

Quality of movement, sometimes referred to as neuromotor control or movement coordination, refers to the biomechanics of the trunk and lower and upper extremities in relation to its surroundings during physical activities (Grabiner et al., 1994) (Piva et al., 2006). Three-dimensional (3D) motion-analysis systems are currently considered the gold standard for the assessment of these abnormal movement patterns (Rabin et al., 2014c). However, regardless of how sensitive and accurate the results from such analyses may be, they are not easily translated to the clinical environment (Rabin et al., 2014a). More importantly, the access to these tools is limited, since clinicians normally do not have the resources to obtain this equipment, nor the time or skills to process the data generated by 3D motion-analysis systems (Jones et al.,

* Corresponding author. Programa de Pós-Graduação em Ciências da Reabilitação, Faculdade de Ciências da Saúde do Trairi (FACISA), Universidade Federal do Rio Grande do Norte (UFRN), Rua Vila Trairi, S/N, Centro, Santa Cruz, RN, CEP: 59200-000, Brazil.
E-mail address: r.scattone@outlook.com (R. Scattone Silva).

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2014) (Rabin et al., 2014a). In this context, clinical tests, with adequate validity and reliability, emerge as important alternatives for the assessment of quality of movement patterns during functional activities.

The lateral step-down test (LSD) has been developed as a simple clinician-friendly tool designed to facilitate the assessment of quality of movement of the lower extremity during a functional activity (Piva et al., 2006). As its name implies, the test requires subjects to perform a step-down maneuver by lowering their leg from the lateral side of a step while the examiner evaluates in a frontal view and scores the quality of the movement (Piva et al., 2006). The test makes it possible for clinicians to identify possible faulty movement patterns, evaluating the behavior of the trunk, hip and knee during the task. Since its creation, the LSD has been used to assess the quality of movement of patients with patellofemoral pain (Piva et al., 2006) (Piva et al., 2009) (Rabin et al., 2014b), ACL reconstruction (Mostaed et al., 2018) and chronic ankle instability (Grindstaff et al., 2017), as well as healthy participants, both sedentary (Chmielewski et al., 2007) (Rabin and Kozol, 2010) (Dannelly et al., 2011) (Rabin et al., 2014a) (Rabin et al., 2014c) (Rabin et al., 2016a) and physically active (Weir et al., 2010) (McMullen et al., 2011) (Jones et al., 2014).

In most studies, the LSD is performed in a similar way: the subjects are asked to stand on the edge of a step with their tested leg, lower their contralateral limb until the heel touches the floor, and go back to the starting position. The task is repeated 5 times and is performed at a self-selected pace (Piva et al., 2006). Piva et al. (2006) have suggested a now largely used 7-point, visual-based, scoring system in order to assess quality of movement during the LSD. The subject's quality of movement is classified as either 'poor', 'medium', or 'good' based on the performance during the test. Subjects are scored based on 5 criteria: arm strategy, trunk movement, pelvis alignment, knee movement and maintenance of a steady unilateral stance (Piva et al., 2006). A few other movement quality classifications have been suggested using the same test (Chmielewski et al., 2007) (Weir et al., 2010) and recently some authors have simplified the classification of quality of movement during the LSD dichotomously, as either 'good' or 'moderate' (Rabin et al., 2014b) (Rabin et al., 2014c). Other authors prefer to classify the movement quality as being 'poor', 'fair' or 'good', also using the LSD but with different classification criteria (Chmielewski et al., 2007). The substantial variability in the different studies makes the interpretation of the LSD quality of movement literature somewhat difficult.

There are several advantages to using the LSD to assess movement quality, especially the fact that it is a quick and easy test to perform in a clinical environment. However, despite being considered a reliable tool by some authors (Piva et al., 2006) (Chmielewski et al., 2007) (Weir et al., 2010) (Rabin et al., 2014b), there is still much conflicting information between studies regarding the details of the test, such as the height of the step and how quality of movement should be assessed. Therefore, the aim of this study is to critically review the literature regarding the assessment of quality of movement during the LSD, and to provide an overview of how this test has been used, describing possible confounding factors and factors associated with altered movement patterns.

2. Methods

A review of the literature was undertaken by means of an electronic search of the following databases: PubMed/MEDLINE, COCHRANE, PEDro, SciELO and LILACS, from inception until June 2018. Given the specific nature of this review, as the only studies that would be considered for the final result needed to include the test in question, the only two terms used for the search were 'lateral step-down' and 'quality of movement', both of which were crossed in between for the final result.

In order to be included in this review, studies needed to be in accordance with the following criteria: 1) use of the LSD for evaluating any population; 2) include the assessment of quality of movement during the LSD, regardless of the method (i.e., purely observational, by numerical scoring and/or through the use of symbols); and 3) English language publication, available in full-text format. Studies that used the lateral step-down for any means other than movement analysis, as well as those that did not include the assessment of quality of movements as part of their investigation, were excluded.

Two reviewers, both physical therapists (RLS and YTP), were responsible for reviewing the titles and abstracts of all retrieved studies individually. Disagreement between reviewers was solved by consensus. If there was no consensus between the reviewers, a third reviewer was consulted about the study's eligibility. The full-text was then obtained for those which were in line with the inclusion criteria. Studies with insufficient information in the title and/or abstract were also obtained in full-text format so that the eligibility could be verified. The reference lists of all selected studies were also examined and if relevant studies were found, their eligibility was also be evaluated.

3. Results

PubMed/MEDLINE, COCHRANE and LILACS were the only databases to feature studies pertinent to this review. Initially, a total of 19 papers were found to meet the inclusion criteria (Piva et al., 2006) (Butler et al., 2007) (Chmielewski et al., 2007) (Piva et al., 2009) (Rabin and Kozol, 2010) (Weir et al., 2010) (Dannelly et al., 2011) (McMullen et al., 2011) (Teyhen et al., 2011) (Jones et al., 2014) (Rabin et al., 2014a) (Rabin et al., 2014b) (Rabin et al., 2014c) (Rabin et al., 2016a) (Rabin et al., 2016b) (Glaviano et al., 2016) (Grindstaff et al., 2017) (Bagherian et al., 2018) (Mostaed et al., 2018). However, after the full-texts of the studies were analyzed, three studies (Butler et al., 2007) (Rabin et al., 2016b) (Glaviano et al., 2016) were excluded, because they did not involve any assessment of quality of movement. Therefore, sixteen studies were ultimately included in the present review.

3.1. Design and participants of the included studies

Fifteen out of the 16 studies were cross-sectional studies. Out of these, 3 involved healthy, sedentary subjects (Chmielewski et al., 2007) (Rabin and Kozol, 2010) (Rabin et al., 2016a), 2 involved healthy military recruits (Teyhen et al., 2011) (Rabin et al., 2014a), 2 involved physically active participants (Dannelly et al., 2011) (McMullen et al., 2011) and 3 involved athletes (Weir et al., 2010) (Jones et al., 2014) (Bagherian et al., 2018). Five studies used the LSD in patients with lower limb conditions, such as patellofemoral pain (Piva et al., 2006) (Piva et al., 2009) (Rabin et al., 2014b), chronic ankle instability (Grindstaff et al., 2017) and ACL reconstruction (Mostaed et al., 2018). The remaining paper was a prospective cohort study with infantry military recruits (Rabin et al., 2014c).

Four studies aimed to determine agreement, reliability and/or measurement of error of specific tests and measurements (Piva et al., 2006) (Chmielewski et al., 2007) (Weir et al., 2010) (Teyhen et al., 2011). Three studies aimed to use the LSD and the assessment of lower limb quality of movement during the test as a measure to investigate of the effects of one or more interventions (Dannelly et al., 2011) (McMullen et al., 2011) (Bagherian et al., 2018). The main characteristics of the selected studies can be found in Table 1 and Table 2.

Table 1
Characteristics of the studies featuring subjects with musculoskeletal injuries included in this review.

Authors	Sample description	Examined measures	Results	Lateral step-down procedure
Piva et al. (2006)	30 patients with patellofemoral pain (13 males and 17 females, average age of 29.1 ± 8.4 years).	Intertester reliability and measurement of error for the following measures: hamstring, quadriceps, plantar flexors and iliotibial band flexibility; tightness of the lateral retinaculum structures; Q-angle; tibial torsion, femoral anteversion, hip external rotation and abduction strength; and quality of movement during the LSD were evaluated.	Reliability coefficients were substantial for measures of hamstring, quadriceps, plantar flexors and iliotibial band length, as well as hip abduction strength and foot pronation; moderate for Q-angle, tibial torsion, hip external rotation strength, lateral retinaculum tightness and quality of movement during the LSD; and poor for femoral anteversion.	**Step height:** 20 cm. **Positioning:** subjects stood on the step with the tested leg, hands on waist, foot close to the edge and contralateral leg positioned over the floor, adjacent to the step. **Movement:** participants bent the tested knee until the contralateral foot touched the floor and then re-extended the knee to the starting position. **Scoring:** 0–6 scale (0–1 'good', 2–3 'medium' and ≥4 'poor' quality of movement).
Piva et al. (2009)	74 patients with patellofemoral pain (35 males and 39 females; average age of 29.0 ± 9.0 years).	Muscle strength, soft tissue length, postural and biomechanical alterations, psychological factors, physical function, pain and quality of movement during the LSD were evaluated.	Fear-avoidance beliefs about work and physical activity were associated with both physical function and pain, while anxiety also demonstrated association with function. None of the other measures showed any association.	**Step height:** 20 cm. **Positioning:** not described. **Movement:** participants bent the tested knee until the contralateral leg touched the floor and then re-extended the knee to the starting position. **Scoring:** 0–6 scale (0–1 'good', 2–3 'medium' and ≥4 'poor' quality of movement).
Rabin et al. (2014b)	79 Israel Defense Forces soldiers with patellofemoral pain (39 males and 49 females; average age of 20.8 ± 1.8 and 19.9 ± 1.5 years, respectively).	Quality of movement during the LSD, as well as ankle dorsiflexion range of motion (in weight-bearing and non-weight bearing conditions), hip internal and external rotation range of motion, and hip abduction, hip external rotation and knee extension strength were evaluated.	Non-weight bearing dorsiflexion range of motion was more limited in males with moderate quality of movement, while weight-bearing range of motion was more limited in both male and female subjects with moderate quality of movement. Quality of movement was associated with weight-bearing range of motion in both males and females and with non-weight bearing range of motion in males. Knee extension and hip external rotation strength was greater in participants with good quality of movement and more than 25° of non-weight-bearing dorsiflexion range of motion.	**Step height:** 15 cm; knee flexion angle was measured during a trial of the test to rule out a possible effect of the step height on the test score. **Positioning:** subjects stood on the step with hands on the waist, tested foot close to the edge, the second toe of the ipsilateral side aligned to a white piece of tape and the non-tested foot hanging off the side. **Movement:** participants bent the tested knee until the contralateral foot reached the floor then re-extended the knee to the starting position. **Scoring:** modified 0–6 scale (0–1 'good' and ≥2 'moderate' quality of movement).
Grindstaff et al. (2017)	59 participants with unilateral and/or bilateral chronic ankle instability (25 males and 34 females; average age of 22.9 ± 2.7 years).	Weight-bearing ankle dorsiflexion range of motion and quality of movement during the LSD were evaluated.	Less ankle dorsiflexion range of motion was found in those with poor quality of movement when compared with those with good quality of movement. There was a negative correlation between ankle dorsiflexion range of motion and quality of movement test scores.	**Step height:** 20 cm. **Positioning:** subjects placed the stance limb close to the edge of the step and kept their hands on their hips. **Movement:** participants were instructed to descend the step, contact the ground with the contralateral leg, and then return to the starting position. **Scoring:** 0–6 scale (0–1 'good', 2–3 'medium' and ≥4 'poor' quality of movement).
Mostaed et al. (2018)	20 participants (2 males, 18 females) with a history of unilateral anterior cruciate ligament reconstruction at least one year prior to recruitment (average age of 24.55 ± 4.61 years)	Weight-bearing ankle dorsiflexion range of motion, International Knee Documentation Committee (IKDC) form score, Tegner Activity Scale score and 2-D and 3-D kinematics and quality of movement during the LSD (with the use of two different box heights - 15 cm in comparison to 10 cm) were evaluated.	2-D quality of movement showed significant correlation with 3-D hip adduction and internal rotation. Subjects with faulty pelvic alignment presented less peak knee flexion; those with faulty knee alignment displayed greater hip adduction. Worse quality of movement was shown when subjects performed the LSD on a higher box (15 cm).	**Step height:** 4 inches (approximately 10 cm) and 6 inches (approximately 15 cm) **Positioning:** subjects stood with the tested leg on the edge of the step, hands on the hips and the contralateral limb hanging off the side of the step with knee in full extension and ankle in full dorsiflexion. **Movement:** participants were asked to bend the tested knee and lower themselves until the contralateral heel touched a force plate on the floor. **Scoring:** 0–6 scale (0–1 'good', 2–3 'medium' and ≥4 'poor' quality of movement).

LSD, lateral step-down test.

Table 2
Characteristics of the studies featuring healthy subjects included in the review.

Authors	Sample description	Examined measures	Results	Lateral step-down procedure
Chmielewski et al. (2007)	25 healthy subjects (7 males and 18 females, average age of 22.4 ± 1.3 years).	Intrarater and interrater agreement for two methods of assessing quality of movement (overall method and specific method) during the lateral step-down and unilateral squat tests were evaluated.	Interrater and intrarater percent agreement were higher using the overall method. Both general and intrarater kappa coefficients were higher for the specific methods, while the interrater weighted kappa coefficients were similar for both methods.	**Step height:** 15.24 cm for subjects under 1.63 m in height, 20.32 cm for participants between 1.63 m and 1.80 m in height and 25.4 cm for those over 1.80 m in height. **Positioning:** subjects stood on the edge of the step with the tested leg, with knee and hip in neutral positions, trunk straight, pelvis leveled, knee extended, hip in slightly flexed position and contralateral leg unsupported. **Movement:** participants lowered themselves at their own pace until the contralateral leg touched the floor and then returned to the starting position. **Scoring:** two scales were used: the overall method, which classified quality of movement as either 'poor', 'fair' or 'good', and the specific method, which used symbols (0, |, √ and X) combined with numerical values (0, 5, 10 and 15 respectively); the higher the number, the worst the quality of movement.
Rabin and Kozol (2010)	29 healthy undergraduate female students (average age of 24.3 ± 3.2 years).	Muscle strength of hip abductors and external rotators, as well as range of motion of ankle dorsiflexion (in both weight-bearing and non-weight bearing conditions), hip external and internal rotations and quality of movement during the LSD were evaluated.	Ankle dorsiflexion range of motion was observed to be decreased in both weight-bearing and non-weight bearing tests among women with moderate quality of movement when compared to those with good quality of movement in the LSD.	**Step height:** 20 cm, adjusted with wood blocks on the side so each participant could reach 60° of knee flexion. **Positioning:** subjects stood on the step with trunk straight, hands on the waist, the tested foot close to the edge, the knee over their second toe (under which there was a 1-cm red sticker) and the non-tested foot hanging off the side with the knee extended and the ankle in maximum dorsiflexion. **Movement:** participants bent the tested knee until the contralateral foot reached either the floor or the wood blocks. **Scoring:** modified 0–6 scale (0–1 'good' and ≥2 'moderate' quality of movement).
Weir et al. (2010)	40 male athletes (average age of 25.4 years, range 18–44 years).	Interobserver and intraobserver reliability of six clinical tests when assessed with a 4-point visual evaluation score were evaluated. Tests were: unilateral squat, lateral step-down, the bridge, frontal plane testing, sagittal plane testing and transverse plane testing.	Intraclass correlation coefficient for interobserver reliability was poor for all tests, except for the unilateral squat and transverse plane testing, which were good. Meanwhile, intraclass correlation coefficient for intraobserver reliability was good for the majority of tests, except for the frontal plane testing and the bridge, which were poor.	**Step height:** 20 cm. **Positioning:** subjects stood on edge of the step with the tested leg, with knee and hip in neutral positions, trunk straight, pelvis leveled, knee extended, hip in slightly flexed position and contralateral leg unsupported. **Movement:** participants lowered themselves at their own pace until the contralateral leg touched the floor and then returned to starting position. **Scoring:** subjects were rated with one of four possible scores ('poor', 'moderate', 'good' or 'excellent' quality of movement).
Dannelly et al. (2011)	26 female undergraduate students (average age of 19.6 ± 1.11 years) were randomized into two groups: open-kinetic chain exercise group (n = 13) and closed-kinetic chain exercise group (n = 13).	Isokinetic concentric peak torque and peak power for knee extension and flexion and shoulder internal and external rotation, as well as 1RM bench press and 1RM leg press, quality of movement during the LSD, Star Excursion Balance Test and maximum sling exercise push-ups were evaluated before and after a 13 weeks of strengthening interventions.	Quality of movement improved after the interventions, but with no difference between groups. Isokinetic and balance tests showed no difference between groups. Leg press and bench press significantly increased in both groups after training.	**Step height:** 20 cm. **Positioning:** subjects stood on the step with hands on the waist, knee straight, weight-bearing foot on the edge of the step and contralateral leg extended over the floor, adjacent to the step. **Movement:** participants bent the tested knee until the contralateral leg touched the floor and then re-extended the knee to the starting position. **Scoring:** 0–6 scale (classification not described in the text, only referencing Piva et al., 2006).
McMullen et al. (2011)	36 healthy and physically active subjects were divided into two groups: 18 males (average age of 22 ± 3.64 years) and 18 females with (average age of 22 ± 3.14 years).	Single-leg static balance (center of pressure measurements), dynamic balance with the Star Excursion Balance Test and quality of movement during the LSD were evaluated before and after a fatigue protocol directed at the gluteus medius.	There was a statistical decrease in postural control and quality of movement after an eccentric fatiguing protocol of the gluteus medius. No significant difference was found between groups (male and female).	**Step height:** 20 cm. **Positioning:** subjects stood on the step with their dominant leg, hands on the hip. **Movement:** participants bent the tested knee until the contralateral leg lightly touched the floor and then re-extended the knee to the starting position. **Scoring:** 0–6 scale (0–1 'good', 2–3 'medium' and ≥4 'poor' quality of movement).
Teyhen et al. (2011)	64 young healthy service members (53 male, 11 female, average age of 25.2 ± 3.8 years)	Reliability of lumbopelvic endurance, flexibility, strength, power and quality of movement during the LSD were evaluated.	Quality of movement displayed a moderate reliability. Measures of strength and power showed moderate to good reliability. Measures of	**Step height:** 20 cm. **Positioning:** subjects stood on the step in a single-leg stance with hands on the waist. **Movement:** participants bent the tested knee until the contralateral leg lightly touched the

Table 2 (*continued*)

Authors	Sample description	Examined measures	Results	Lateral step-down procedure
			flexibility had limited reliability. Lumbopelvic endurance showed good reliability, but with large standard errors of measurement.	floor and then re-extended the knee to the starting position. **Scoring:** 0–5 scale (0 'good', 5 'poor' quality of movement)
Jones et al. (2014)	81 division I collegiate female athletes from basketball, lacrosse, soccer and volleyball teams who underwent preseason musculoskeletal screening (average age of 19.4 ± 2.4 years).	Knee abduction angle (with a 3-D motion-capture system) and frontal place projection angle (with 2-D digital video) were evaluated during the LSD.	Knee abduction angle did not differ between participants across different observational rating groups, while frontal plane projection angle was significantly different between all observational groups, with a tendency for higher results in the 'poor' group and lower values in the 'good' group.	**Step height:** 15 cm for subjects under 1.67 m in height, 20 cm for participants between 1.67 m and 1.83 m in height and 25 cm for those over 1.83 m in height. **Positioning:** subjects stood on the tested leg with hands on their hips and maintaining an upright chest, level pelvis, knee over the second toe and foot flat on the step. **Movement:** participants lowered their bodies slowly until the contralateral heel touched the floor and then returned to the starting position. **Scoring:** 0–6 scale (referenced Piva et al., 2006, but did not describe the scoring method in the text).
Rabin et al. (2014a)	55 healthy male Israeli military recruits (average age of 19.7 ± 1.1 years).	Dorsiflexion range of motion in both weight-bearing and non-weight bearing conditions, as well as quality of movement during the LSD were evaluated.	Weight-bearing and non-weight bearing ankle dorsiflexion range of motion in the dominant leg were more limited in subjects with moderate quality of movement; these also showed more limited results of non-weight bearing range of motion in the non-dominant leg. Range of motion in both conditions correlated significantly with quality of movement in both legs.	**Step height:** 15 cm. **Positioning:** subjects stood on the step with trunk straight, hands on the waist, the tested foot close to the edge, the knee of the ipsilateral side over their second toe (under which there was a piece of black tape) and the non-tested foot hanging off the side. **Movement:** participants bent the tested knee until the contralateral foot reached the floor without any weight put in it and then re-extended the knee to the starting position. **Scoring:** modified 0–6 scale (0–1 'good' and ≥2 'moderate' quality of movement).
Rabin et al. (2014c)	70 healthy male military recruits (average age of 19.6 ± 1.0 years).	Ankle dorsiflexion range of motion in both weight-bearing and non-weight bearing conditions, as well as quality of movement assessment during the LSD were evaluated. The development of Achilles tendinopathy was recorded after six months of army basic training.	Five participants developed Achilles tendinopathy. All of these had more limited non-weight bearing ankle dorsiflexion range of motion. Quality of movement did not differ between injured and uninjured recruits.	**Step height:** 15 cm. **Positioning:** subjects stood on the step with trunk straight, hands on the waist, the tested foot close to the edge, the knee of the ipsilateral side over a their second toe (under which there was a piece of black tape) and the non-tested foot hanging off the side. **Movement:** participants bent the tested knee until the contralateral foot reached the floor without any weight put in it and then re-extended the knee to the starting position. **Scoring:** modified 0–6 scale (0–1 'good' and ≥2 'moderate' quality of movement).
Rabin et al. (2016a)	30 healthy participants (10 males and 20 females; average age of 25.8 ± 2.9 years).	Trunk, pelvis and knee alignment was assessed and rated during the LSD. Trunk, pelvis, hip and knee 3-D kinematics, as well as quality of movement during the LSD, were also evaluated.	Participants with faulty pelvis alignment in the LSD showed greater contralateral peak pelvic drop and greater peak hip adduction. Those with faulty knee alignment in the LSD displayed greater peak knee external rotation. Increased peak contralateral pelvic drop and peak knee external rotation were found in those with a moderate quality of movement in relation to those with good quality of movement.	**Step height:** 15 cm. **Positioning:** subjects stood with the hands on the wait, right leg close to the edge of the step and left leg hung straight off the side of the step. **Movement:** participants were instructed to lower their bodies until the left heel touched the floor and then return to the starting position. **Scoring:** modified 0–6 scale (0–1 'good' and ≥2 'moderate' quality of movement). 'Arm strategy' and 'steady stance' were not considered for quality of movement assessment.
Bagherian et al. (2018)	100 active and healthy male collegiate athletes (40 from basketball, 40 from futsal, 12 from volleyball and 8 from martial arts) were divided into intervention group (average age of 18.10 ± 0.9 years) and control group (average age of 18.03 ± 0.9 years).	Functional Movement Screen, the LSD and the Y balance test were evaluated before and after an 8-week core-training program emphasizing functional movement patterns.	Improvements were found in the intervention group for the Functional Movement Screen, LSD and Y balance test. Greater improvement was found in those with worse movement quality in the Functional Movement Screen and Hurdle step tests.	**Step height:** 15 cm. **Positioning:** subjects stood on the step with trunk straight, hands on the waist and knee of the stance leg over the second toe of the ipsilateral side while looking ahead. **Movement:** participants were asked to bend the knee of the stance leg until the contralateral heel touched the floor next to the step without putting any weight on it, and then re-extend the knee and return to the starting position. **Scoring:** 0–6 scale (0–1 'good', 2–3 'medium' and ≥4 'poor' quality of movement).

LSD, lateral step-down test; RM, repetition maximum.

3.2. Scoring of the lateral step-down test

Regarding the final score of the LSD, the original study that developed the test described five criteria for assessing quality of movement (Piva et al., 2006). The participant's movement during the lateral step-down maneuver was evaluated and points were added to the final score when: 1) subjects used an arm strategy in order to regain balance (arm strategy – one point); 2) the trunk leaned to any side (trunk strategy – one point); 3) the pelvis dropped, rotated or elevated to either side when compared to the other (pelvis alignment – one point); 4) the knee moved medially and the tibial tuberosity crossed an imaginary line over the second toe (knee movement – one point) or crossed the medial border of the foot (two points) and 5) the subject displayed any sort of unbalanced stance, either stepping down from the non-tested side or wavering from side to side on the tested side (steady unilateral stance maintenance – one point) (Piva et al., 2006). Points were given for movement abnormalities according to these criteria and the total score was divided into 3 different categories: subjects who scored 0 or 1 were classified as having 'good' quality of movement, subjects who scored 2 or 3 were classified as having 'medium' quality of movement and those who scored between 4 and 6 were classified as having 'poor' quality of movement (Piva et al., 2006).

Out of the included articles, eight used the classification system described above (Piva et al., 2006) (Piva et al., 2009) (Dannelly et al., 2011) (McMullen et al., 2011) (Jones et al., 2014) (Grindstaff et al., 2017) (Bagherian et al., 2018) (Mostaed et al., 2018). Five studies modified this scoring system, using only two final classifications of quality of movement: 'good', for subjects with scores between 0 and 1, and 'moderate', for those with scores above 2 (Rabin and Kozol, 2010) (Rabin et al., 2014a) (Rabin et al., 2014b) (Rabin et al., 2014c) (Rabin et al., 2016a). This adaptation was proposed because, in these studies, only a few participants were considered to have a 'poor' quality of movement, with scores above 3.

Two alternative scales have been described with the purpose of assessing lower limb quality of movement during a lateral step-down task, similar to the LSD (Chmielewski et al., 2007) (Weir et al., 2010). Chmielewski et al. (2007) evaluated the intrarater and interrater agreement for two quality of movement scoring methods during a lateral step-down task: an overall method and a specific method. The overall method scoring system was similar to that proposed by Piva et al. (2006) since it classified subjects into 3 categories depending on 'movement deviations': 'poor' indicating the existence of large movement deviations, 'fair' indicating barely-observable deviations and 'good' representing no movement deviations (Chmielewski et al., 2007). In the specific method scoring system, raters were to score each segment (trunk, pelvis and hip) separately and the severity of movement deviation was registered using four different symbols: '0' meaning no deviation from neutral alignment, '|' indicating a small or barely-observable deviation from the neutral position or lower limb oscillations in a low frequency, '√' representing a moderate or marked movement out of the neutral position or lower limb oscillations in a moderate frequency and 'X' indicating excessive or severe magnitude of movement from the neutral position or lower limb oscillations in a high frequency. Each symbol also corresponded to a numerical equivalent: 0, 5, 10 and 15, respectively. The scores were to be interpreted as the higher the number, the greater the movement deviation (Chmielewski et al., 2007).

3.3. Categorization of the studies and possible confounding factors

Studies included in this review were categorized into studies with healthy participants (Table 1) and studies with participants with musculoskeletal conditions (Table 2). The descriptions of the LSD procedure and how the procedures were performed in each study are also presented in four subcategories: step height, positioning (how the subjects were positioned before performing the lateral step-down movement), instruction (which instructions were given and how the task was actually performed) and method of scoring (which scale was employed for assessment of quality of movement) (Tables 1 and 2). These subcategories were chosen for a clearer presentation of how the LSD is being used and to identify possible confounding factors which might exist across the different studies in the literature.

4. Discussion

Despite being described in the literature for over a decade (Piva et al., 2006), the LSD has been used in few studies, even though it is considered a reliable tool for the evaluation of lower extremity movement. As seen in this review, the LSD is most commonly used to assess the movement of healthy subjects (Chmielewski et al., 2007) (Rabin and Kozol, 2010) (Weir et al., 2010) (Dannelly et al., 2011) (McMullen et al., 2011) (Jones et al., 2014) (Rabin et al., 2014a) (Rabin et al., 2014c) (Rabin et al., 2016a) (Bagherian et al., 2018). Only a limited number of studies have chosen this test for the evaluation of lower extremity movements of patients with lower limb injuries, such as patellofemoral pain (Piva et al., 2006) (Piva et al., 2009) (Rabin et al., 2014b), chronic ankle instability (Grindstaff et al., 2017) and ACL reconstruction (Mostaed et al., 2018). A clear understanding of the different ways that the LSD has been used, its reliability and factors associated with its results are important for clinicians and researchers to be able to properly interpret the existing literature on this matter.

4.1. Reliability of different LSD scoring methods for assessment of quality of movement

Piva et al. (2006) were the first authors to propose a scale for assessment of quality of movement during the LSD in a study investigating the intertester reliability and measurement error of the movement quality in patients with patellofemoral pain. Assessment of quality of movement during the LSD was found to have a moderate intertester reliability [Kappa (κ) = 0.67], which is acceptable for a tool to evaluate movement in a clinical environment (Piva et al., 2006).

Rabin and Kozol (2010) have proposed a simplified final classification for this test, using only two final classifications of quality of movement: 'good', for subjects with scores between 0 and 1, and 'moderate', for those with scores above 2. Using this simplified classification system, moderate to excellent reliability has been observed for the LSD in five studies, with $\kappa = 0.59–0.81$ (Rabin and Kozol, 2010) (Rabin et al., 2014a) (Rabin et al., 2014b) (Rabin et al., 2014c) (Rabin et al., 2016a). Future studies should take notice that this simplified classification system is an option to improve classification in cases where there is insufficient numbers of subjects in one of the quality of movement categories.

Teyhen et al. (2011) investigated the reliability of quality of movement assessment in a population of military soldiers using another adaptation of the original scale. Instead of using the original 0 to 6 points scale, described by Piva et al. (2006), the examiners chose to exclude one of the criteria of the original scoring system (maintenance of steady unilateral position) and scored subjects with points ranging from 0 to 5. The reliability of this adapted scoring system was found to be moderate ($\kappa = 0.61$) (Teyhen et al., 2011).

As previously described, Chmielewski et al. (2007) described two other quality of movement evaluation methods, an overall method and a specific method. None of these methods, however,

produced a high agreement in their reliability tests. Agreement between raters for the lateral step-down task ranged from 41% to 82% for the overall method ($\kappa = 0.00–0.55$) and 20%–50% for the specific method ($\kappa = 0.23–0.53$). Intrarater percent agreement ranged from 56% to 76% for the overall method ($\kappa = 0.13–0.50$) and 32%–60% for the specific method ($\kappa = 0.38–0.68$) (Chmielewski et al., 2007). These movement quality scoring methods have not been used since the study by Chmielewski et al. (2007), potentially because the reliability of these methods was considered low.

Another method for assessment of quality of movement was proposed by Weir et al. (2010) in a study investigating the inter-observer and intraobserver reliability of 6 clinical tests for 'evaluation of core stability', including the LSD. Each examiner of the study was instructed on how to rate the tests and scores were split into 4 categories: 'poor' (excessive movement deviation out of a neutral position or high-frequency oscillatory segment movements), 'moderate' (moderate movement deviation and oscillatory segment movements), 'good' (small or barely observable movement deviation or low-frequency oscillatory segment movements) and 'excellent' (no deviation from neutral alignment). Intraobserver reliability was found to be fair ($ICC_{2,1} = 0.49$), while interobserver reliability was deemed poor ($ICC_{2,1} = 0.39$) (Weir et al., 2010). The low reliability found by the authors might be the reason why no other study has used this classification system to assess quality of movement.

4.2. Factors associated with quality of movement during the LSD

A few lower limb strength and flexibility deficits have been associated with worst quality of movement, assessed by the LSD; specifically, reduced dorsiflexion range of motion (Rabin et al., 2014a) (Rabin et al., 2014b) (Grindstaff et al., 2017) and strength of the hip external rotators and knee extensors (Rabin et al., 2014b). These factors are briefly discussed next.

A study involving men and women with patellofemoral pain aimed to determine which lower limb strength and flexibility variables are associated with the quality of movement in this population (Rabin et al., 2014b). Weight-bearing and non-weight bearing ankle dorsiflexion range of motion, hip external and internal range of motion and hip abduction, external rotation and knee extension strength were evaluated. These measures were then compared between participants with good and moderate quality of movement during the LSD. The authors found that both weight-bearing and non-weight bearing ankle dorsiflexion ranges of motions were limited in men with moderate quality of movement in comparison to those with good quality of movement (Rabin et al., 2014b). Weight-bearing ankle dorsiflexion range of motion was also more limited in females with moderate quality of movement in relation to females with good quality of movement in the LSD. A negative correlation between the LSD and weight-bearing ankle dorsiflexion range of motion was observed in both sexes ($r = -0.39$, $P = 0.01$ for females and $r = -0.46$, $P < 0.01$ for males), as well as between the LSD and non-weight bearing ankle dorsiflexion range of motion for males ($r = -0.66$, $P < 0.01$) (Rabin et al., 2014b). Corroborating with these findings, in a study with healthy male military recruits, reduced weight-bearing ankle dorsiflexion range of motion was associated with worst quality of movement during the LSD both in the dominant and non-dominant lower limbs of the participants (Rabin et al., 2014a).

More recently, Grindstaff et al. (2017) investigated differences in ankle dorsiflexion range of motion between individuals with different lower limb qualities of movement, including patients with chronic ankle instability. Participants with poor quality of movement were found to have, on average, 6° less weight-bearing ankle dorsiflexion range of motion than those with good quality of movement. The authors also found a negative correlation ($r = -0.39$; $P = 0.002$) between ankle dorsiflexion range of motion and the LSD scores (Grindstaff et al., 2017).

Strength of the hip and knee muscles also seems to be important for a better quality of movement during the LSD. In a recent study, military recruits were evaluated with regards to quality of movement during the LSD, hip abduction, hip external rotation and knee extension strength (Rabin et al., 2014b). It was observed that participants with greater strength of the knee extensors and hip external rotators had better quality of movement during the LSD. These results are not surprising, since strength of the knee extensors and hip external rotators are important to control knee flexion and hip internal rotation during weight-bearing activities, respectively (Rabin et al., 2014b). Fast, uncontrolled knee flexion and excessive hip internal rotation would likely lead to abnormal movement patterns and reflect in higher scoring in the LSD (steady unilateral stance maintenance and knee movement criteria, specifically).

Collectively, these results indicate that deficits in knee extension and hip external rotation strength, as well as in ankle dorsiflexion range of motion, are associated with worst quality of movement, and should be considered as potential contributors to this faulty movement pattern. In this context, interventions aimed at improving dorsiflexion range of motion and knee extensors and hip external rotators strength might be important for improving quality of movement in weight-bearing activities, such as the one evaluated in the LSD.

4.3. Possible confounding factors

A few important confounding factors have been identified in this review and are presented next, in an attempt to raise awareness on them for clinicians and researchers. These confounding factors include step height, lack of pace control on the step-down task, and lack of a standard in instructions and participant positioning prior to the test.

Height of the step is one of the most important potential confounding factors, as it tends to vary significantly between studies and there is no standard that can be evidenced from reviewing all studies. Piva et al. (2006) originally suggested a step with 20-cm of height, which was also used by other studies (Piva et al., 2009) (Weir et al., 2010) (Dannelly et al., 2011) (McMullen et al., 2011) (Grindstaff et al., 2017). Rabin and Kozol (2010) also used 20-cm steps, but included wooden blocks on the side so that the participants could only lower their body until 60° of knee flexion was reached during the test. Other studies have chosen to use a 15-cm step (Rabin et al., 2014a) (Rabin et al., 2014b) (Rabin et al., 2014c) (Rabin et al., 2016a) (Bagherian et al., 2018). The reasoning for the use of a 15-cm is that it is an optimal height for most people to reach 60° of knee flexion during the test (Rabin et al., 2014b).

Other authors have adjusted the step height according to the height of the participants (Chmielewski et al., 2007) (Jones et al., 2014). Chmielewski et al. (2007) used steps that ranged from 15.24 cm to 25.40 cm. Subjects under 1.63 m in height used a 15.24 cm step, those between 1.63 m and 1.80 m in height used a 20.32 cm step and those over 1.80 m in height used a 25.40 cm step. Jones et al. (2014) used a modified version of this protocol, with steps ranging from 15 to 25 cm. Participants under 1.67 m in height used the 15 cm step, while those between 1.67 m and 1.83 m in height used a 20 cm step; and those over 1.83 m in height used a 25 cm step (Chmielewski et al., 2007). None of the authors, however, clarify the reasoning behind the use of these protocols.

Recently, Mostaed et al. (2018) used two step heights (10 cm and 15 cm) in the evaluation of quality of movement during the LSD, and compared the results of the assessments between both heights

as part of their study. The authors found that the 15 cm step elicited worse quality of movement in general when compared to the 10 cm step (Mostaed et al., 2018). These results indicate that step height can significantly influence movement quality, and should not be neglected as a potential source of conflicting findings.

Another important confounding factor is the fact that most studies do not control the pace of the lateral step-down maneuver task during the LSD (Piva et al., 2006) (Chmielewski et al., 2007) (Piva et al., 2009) (Rabin and Kozol, 2010) (Weir et al., 2010) (Dannelly et al., 2011) (McMullen et al., 2011) (Teyhen et al., 2011) (Rabin et al., 2014a) (Rabin et al., 2014b) (Rabin et al., 2014c) (Rabin et al., 2016a) (Grindstaff et al., 2017) (Bagherian et al., 2018) (Mostaed et al., 2018). Managing the pace of movement during the test might be important, since the performance of the task in a fast manner may require less control of the muscles to maintain the alignment of the pelvis and lower limb joints. A slower execution of the step-down maneuver also allows the examiner to better observe possible altered movement patterns and score each aspect of the assessment of quality of movement properly.

The positioning of the participants before the test was originally proposed to be the following: participant standing on the step with the full weight on the tested leg, hands on waist, foot close to the edge of the step and contralateral leg positioned over the floor adjacent to the step (Piva et al., 2006). This initial position was similar between all studies, although a few studies also used more detailed descriptions regarding the alignment of the trunk, hip, knee, pelvis and foot (Chmielewski et al., 2007) (Rabin and Kozol, 2010) (Weir et al., 2010) (Jones et al., 2014) (Rabin et al., 2014a).

Regarding instructions for performance of the LSD, although in most studies the examiner provided only basic instructions for the performance of the test, in the study by Jones et al. (2014) participants were cued to maintain an upright chest, level pelvis, knee over second toe, and foot flat on the step during the test. These verbal instructions are likely to be confounding factors, since they potentially influence the movement pattern of the participant during the task. Future studies should consider only providing the subjects with the basic instructions for the performance of the test, similarly to what was originally proposed by Piva et al. (2006). Allowing the subjects to perform the test freely might reduce the risk of bias and provide more realistic results in regards to an individual's actual lower limb quality of movement.

Although the LSD is considered a clinician-friendly, reliable tool, studies including the use of the LSD for assessment of lower extremity quality of movement are still scarce, especially in populations with musculoskeletal conditions. Future investigations should consider the possible confounding factors that might occur with the use of adapted versions of the LSD, as there is a lack of standard about how the test should be performed, from the height of the step to the instructions given to the subjects prior to undertaking the procedure. Further studies with more methodological uniformity are recommended.

4.4. Limitations

This review has limitations, considering that it is not an exhaustive systematic review of the topic. Narrative reviews are inherently subjective, with limitations such as the bias of study selection. These results are also specific to young individuals and the generalization of these findings to other populations should be made with caution.

5. Conclusion

In conclusion, the literature suggests that the LSD is a reliable, simple and easy-to-learn tool that can be used, on the field, for research or in a clinical environment, to quantify lower extremity quality of movement. Future studies should employ this tool in different populations in order to assess the quality of movement of subjects with a wide variety of musculoskeletal conditions. However, standard methods should be used, both for application, scoring and interpretation of the test, so that confounding factors can be minimized.

6. Clinical relevance

- The lateral step-down test (LSD) is a simple tool for the assessment of lower extremity quality of movement;
- The LSD has adequate reliability and it is a quick and easy test to perform in a clinical environment;
- Worst quality of movement during the LSD has been associated with deficits in hip external rotation and knee extension strength and in ankle dorsiflexion range of motion;
- Although frequently used in the literature, significant variability exists in the way the LSD is applied, scored and interpreted;
- Confounding factors in the use of the LSD include step height, lack of pace control and lack of standard in instructions and positioning prior to the test. Attention to these details is important for adequate interpretation of the LSD results.

Declaration of interest

None.

Conflicts of interest declaration

There were no conflicts of interest in the development of this review.

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