



# LUMBAR SPINE, PELVIS, AND HIP SIT-TO-STAND ASSESSMENT PROTOCOLS AND ROM REFERENCE VALUES: A SYSTEMATIC REVIEW WITH META-ANALYSIS

review paper

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## ABSTRACT

**Purpose.** The evaluation of the sit-to-stand (STS) movement has been widely studied; however, very different protocols are used, making it difficult to choose a methodology. So, the purposes of this study were: (1) to identify the STS movement assessment protocols for lumbar spine, pelvis, or hip on the basis of video image analysis; (2) to investigate the reference values for these regions range of motion (ROM) using a systematic review with meta-analysis.

**Methods.** The searches were conducted in BIREME, Embase, PubMed, ScienceDirect, Scopus, and Web of Science databases; manual searches were also performed. Two independent reviewers selected the studies, extracted the data, and assessed the methodological quality and risk of bias. The methodological quality was verified by the Downs and Black scale and the strength of evidence by the GRADE system. Seventeen studies were included, from which data on sample, evaluation protocols, and ROM angles were extracted.

**Results and conclusions.** The studies showed high strength of evidence. Acquisition protocols diverged, but most of the studies utilized 3D video image analysis with optoelectronic systems, backless seat with adjustable height, and asking the subject to perform 3 trials of the movement in self-referred speed, keeping the arms crossed. The meta-analysis provided reference values for adults hip ROM (compared with the thigh) of 81.19–93.71°. For the elderly, the angles for lumbar spine and hip position at the start of the STS movement were 0.20–3.99° and 73.58–78.06°, respectively.

**Key words:** sit-to-stand, spine, pelvis, review

## Introduction

The sit-to-stand (STS) movement represents one of the many functional activities and it is considered an ordinary and very representative task of the daily living [1]. Rising from the sitting position can be defined as a movement of transition to the erect posture through a change in the centre of body mass from a stable position to a less stable one. This movement ends with the extension of the lower limbs while the body keeps the balance on a small support base [2].

The analysis of the STS movement requires basic knowledge of the facts that influence its performance and phenomena determining the task completion. These are divided into 3 groups: related to the chair,

related to the subject, and related to the strategy. The factors related to the chair comprise the seat height, the armrest, the backrest, and special chairs [3–5]. The factors related to the subject are age, illnesses, graduation of muscle strength, and utilization of shoes [6]. The factors related to the strategy come from the standing up movement: speed, feet position, utilization of the armrest, arms movement, joints stabilization in general, knee position, final restriction of movement, visual control, attention during the movement, training, position, and movement of the trunk [7, 8].

Kinematics is predominant among the most utilized movement assessment methods [1, 9, 10]; therefore, image analysis with a computer system is largely applied [8]. So, despite the variability of acquisition pro-

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protocols for range of motion (ROM) for the lumbar spine, pelvis, or hip, there are no reference values for these variables. Besides, a great number of studies do not evaluate the role of the lumbar spine, pelvis, or hip in the STS movement [11]. Thus, the purposes of this study were to (1) identify the STS movement assessment protocols for lumbar spine, pelvis, or hip on the basis of video image analysis; (2) investigate the reference values for these regions ROM using a systematic review with meta-analysis.

**Material and methods**

Study design

The study presents a literature review directed by the PRISMA statement [12] in accordance with the recommendations of the Cochrane Collaboration and registered in the PROSPERO database (registration number: CRD42015029960, access link: [http://www.crd.york.ac.uk/PROSPERO/display\\_record.asp?ID=CRD42015029960](http://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42015029960)).

Search strategies

Systematic searches were conducted in accordance with the Cochrane Collaboration recommendations [13] in the BIREME, Embase, PubMed, ScienceDirect, Scopus, and Web of Science databases by the 21<sup>st</sup> February, 2017. The keywords used and the respective Boolean operators were *Spine* [OR] *Pelvis* [AND] *Sit-to-stand*. The strategy to search the PubMed database is visualized in Table 1. The date of publication was not restricted, but the languages were limited to English, Spanish, and Portuguese. Moreover, some studies identified in the references were also included in the screening.

Two independent reviewers selected the potentially relevant studies after reading titles and abstracts. When an abstract contained not enough information, the entire article was read. After this, the same reviewers independently screened the full studies, selecting them

in accordance with the eligibility criteria: (1) design – observational study or clinical trial; (2) kinematic evaluation of the ROM and angular values for the lumbar spine, pelvis, or hip through video analysis; (3) evaluation of sitting down, standing up, or both movements; (4) evaluation of healthy subjects; (5) language: Brazilian Portuguese, Spanish, or English. Discrepancies were resolved by consensus and, when necessary, a third reviewer was included [14].

Data extraction, quality assessment, and risk of bias

Only included studies underwent data extraction, quality appraisal, and risk of bias analysis. The second phase, data extraction, was performed independently by the same reviewers, and discrepancies were resolved by consensus. Information was extracted with a standardized form and included: first author’s name, publication year, participants (healthy subjects), assessment protocol, and variables of interest (Tables 2–5).

The methodological quality of the included studies was evaluated by the Downs and Black checklist, which consists of 27 items and attributes 1 point to a study when the answer to the criteria is yes and the item is fulfilled, or 0 points when the answer is no and the item is not fulfilled. The checklist is an adaptable instrument that can assess observational studies and clinical trials besides presenting reproducibility and internal consistency; those were the reasons why it was chosen. All items must be considered in the assessment of clinical trials. However, in this review, only observational studies were included and only 12 items of the checklist were taken into account (Table 6). The studies were ascribed high methodological quality if they fulfilled at least 60% of the items considered in the assessment. As previously, in this third step, the methodological quality was determined independently by the same 2 reviewers and discrepancies were resolved by consensus.

Table 1. Strategy to search the PubMed database

#4 Search (#1 OR #2 AND #3)
#3 Search ('Sit-to-stand' OR 'Stand-to-sit' OR 'Sit to stand' OR 'Stand to sit' OR 'Sitting to standing' OR 'Sit-to-stance-to-sit' OR 'Sitting' OR 'Sit-stand-sit' OR 'Back-to-sit' OR 'Pattern of movement')
#2 Search ('Pelvis'[Mesh] OR 'Pelvis' OR 'Pelvic Region' OR 'Region, Pelvic')
#1 Search ('Spine'[Mesh] OR 'Spine' OR 'Vertebral Column' OR 'Column, Vertebral' OR 'Columns, Vertebral' OR 'Vertebral Columns' OR 'Spinal Column' OR 'Column, Spinal' OR 'Columns, Spinal' OR 'Spinal Columns')

Study inclusion

## Statistical analysis

Data were analysed by descriptive statistics and divided in subgroups with the consideration of the angular variable, video image analysis, and methodology. The meta-analysis was performed with the MedCalc Statistical Software v. 18 (MedCalc Software, Ostend, Belgium) by inputting mean and standard error. The Higgins' test of inconsistency ( $I^2$ ) was applied to evaluate inter-studies heterogeneity and the result was considered low if  $I^2 < 50\%$  or moderate/high if  $I^2 \geq 50\%$  [12].

## Strength of evidence

The GRADE (Grading of Recommendations Assessment, Development and Evaluation) system was utilized to rate the quality of evidence and recommendation strength provided by the systematic review. It considers the following criteria for the studies included: study design, methodological limitations, inconsistency (homogeneity of the studies), direct evidence, results' accuracy, existence of publication bias for not including the totality of published studies concerning the issue of research [15].

On the basis of the criteria established, the GRADE system classifies the evidence level as: high quality – additional research will very unlikely change the results presented by the systematic review; moderate quality – further research will probably cause important impact and could change the results presented by the systematic review; low quality – further research will very likely cause impact and will probably alter the results presented by the systematic review; very low quality – any estimate of the results presented by the systematic review is uncertain and requires new studies.

## Results

In the databases searched, 4751 studies were found and 21 studies were included by manual searches. Duplicates (2561) were removed and 2211 studies had the title and the abstract screened. In this phase, 2161 studies did not meet the eligibility criteria and the rest of 50 studies were read entirely. Only 17 studies fulfilled all the eligibility criteria and were included in the review. Figure 1 shows the flow diagram of inclusion stages in accordance with the PRISMA recommendations [12].

Tables 2 and 3 summarize the main STS and STS/stand-to-assessment protocols found in the included studies ( $n = 17$ ). Tables 5 and 6 show the angular values and ROM for lumbar spine, pelvis, and hip. The score of the methodological quality presented by the studies is

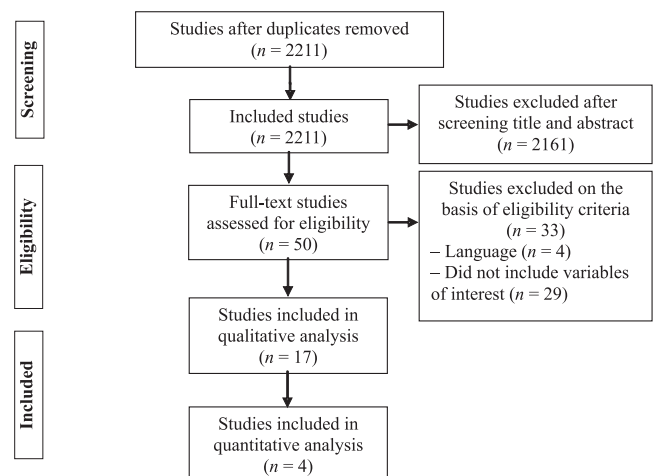


Figure 1. Flow of information through the different phases of the systematic review with meta-analysis in accordance with the PRISMA recommendations [12]

depicted in Table 6. All included articles had a cross-sectional study design.

On the basis of the assessment of the overall quality of evidence for the 17 involved studies, 12% ( $n = 2$ ) scored low quality. Also, taking into account the heterogeneity of the studies regarding the methodological rigor, only 4 studies could be included in the meta-analysis (Tables 7–12). So, further research is likely to have an important impact on the outcomes of this review and may change the results found for the angular values and ROM reference values of lumbar spine, pelvis, and hip during the STS and STS/stand-to-sit movements. In this way, in agreement with the GRADE rating, this review has moderate quality of evidence [15].

## Discussion

With the purpose of helping the choice among the STS assessment protocols for the lumbar spine, pelvis, or hip regions, some important issues need to be taken into consideration.

### Video image analysis and performance parameters

The 3D systems guarantee precise quantification of true spatial movements because they eliminate the perspective error, but the procedures and analyses are more complicated and demand more equipment requisites [30]. However, the option for validated 2D systems can be interesting [31]. Also, frequency rates above 100 Hz are desirable because they assure capturing minimum linear and angular shifts in a joint

Table 2. Protocols used to evaluate the movement of standing up from the sitting position (indexed by video image analysis and by author)

1 <sup>st</sup> author (year) and sample (age range, years)	Video image analysis and performance parameters	Movement phases and description of angular measurement	Anatomical landmarks (for lumbar, pelvic, and hip variables)
Anan (2008) [17] n = 11 (79–87)	<ul style="list-style-type: none"> <li>• 2D – 1 camera, NHI Image (30 frames/s)</li> <li>• Backless seat: head of fibula height</li> <li>• Vertical shanks</li> <li>• Barefoot subjects</li> <li>• Medial border of the feet 40°</li> <li>• Crossed arms</li> <li>• Look forward instruction, no visual target</li> <li>• 3 trials (those considered symmetrical by subject and evaluator)</li> <li>• 4 sitting conditions: no cushion (0 mm), 30-, 60-, and 90-mm height cushion</li> </ul>	<ul style="list-style-type: none"> <li>• Complete STS movement</li> <li>• Pelvic angle in relation to the horizontal plane</li> <li>• Hip angle in relation to the horizontal plane</li> </ul>	Unilateral: <ul style="list-style-type: none"> <li>• acromion</li> <li>• the lowest rib</li> <li>• ASIS/PSIS</li> <li>• greater trochanter</li> <li>• lateral knee joint line</li> </ul>
Fotoohabadi (2010) [11] n = 41 (64–75)	<ul style="list-style-type: none"> <li>• 2D – 1 camera, Peak Motus system</li> <li>• Backless seat with adjustable height: 100% shank height</li> <li>• Barefoot subjects</li> <li>• Feet position: back/forward defined by the subject</li> <li>• Crossed arms</li> <li>• 3 trials</li> <li>• Only the 'smoothest' trial was analysed</li> <li>• Self-selected speed</li> </ul>	<ul style="list-style-type: none"> <li>• Start: 10% increase in the horizontal displacement of the T1 marker</li> <li>• Seat-off : 10% increase in the vertical displacement of the proximal 2/3 thigh marker</li> <li>• End: the point of no further hip extension</li> <li>• Lumbar angle: angle between the line defined by T11–L1 and the line perpendicular to the pelvic plane<sup>a</sup></li> <li>• Hip angle: between the long axis of the femur (2/3 thigh–supracondylar markers) and the pelvic plane<sup>a</sup></li> </ul>	Unilateral: <ul style="list-style-type: none"> <li>• T11, L1</li> <li>• ASIS/PSIS</li> <li>• proximal 2/3 thigh</li> <li>• above the lateral condyle of the femur</li> </ul>
Tully (2005) [18] n = 47 (18–30)	<ul style="list-style-type: none"> <li>• 2D – 1 camera, Peak Motus system (50 frames/s)</li> <li>• Backless seat with height adjustable: shank length (mid-line knee)</li> <li>• Barefoot subjects</li> <li>• Crossed arms</li> <li>• Self-selected speed</li> <li>• Repeated until performance without unwanted or unnatural actions</li> </ul>	<ul style="list-style-type: none"> <li>• Start: with the horizontal displacement of the T1 marker</li> <li>• Seat-off: 10% of the vertical displacement of the proximal (2/3 Th) thigh marker</li> <li>• End: maximal vertical displacement of the T1 marker</li> <li>• Lumbar angle: angle between the line defined by T11–L1 and the line perpendicular to the pelvic plane<sup>a</sup></li> <li>• Hip angle: between the long axis of the femur (2/3 thigh–supracondylar markers) and the pelvic plane<sup>a</sup></li> </ul>	Unilateral: <ul style="list-style-type: none"> <li>• L1</li> <li>• 3 cm proximal to L1</li> </ul> Bilateral: <ul style="list-style-type: none"> <li>• ASIS/PSIS</li> <li>• 2/3 thigh</li> <li>• supracondylar thigh</li> </ul>
Gilleard (2008) [19] n = 12 (24–33)	<ul style="list-style-type: none"> <li>• 3D – 8 cameras, Expert Vision (60 Hz)</li> <li>• Seat height: 110% of fibular head distance to the floor</li> <li>• Arms beside the body</li> <li>• Visual target</li> <li>• 3 trials, repeated on 3 occasions 16 weeks</li> <li>• Apart</li> <li>• Self-selected speed</li> </ul>	<ul style="list-style-type: none"> <li>• Start: the horizontal velocity of the great humeral tubercle marker was <math>\geq 10</math> mm/s and the marker did not move in the vertical direction</li> <li>• Seat-off: maximum right posterior ground reaction force</li> <li>• End: maximal knee extension and maximal vertical displacement of the right great humeral tubercle marker</li> <li>• Hip: midpoint between left and right ASIS and left and right PSIS</li> </ul>	Bilateral: <ul style="list-style-type: none"> <li>• ASIS/PSIS</li> <li>• apex of sacrum</li> <li>• subtrochanter</li> <li>• mid thigh (10 cm above the patella)</li> <li>• lateral femoral epicondyle</li> </ul>
Cacciatore (2011) [20] n = 30 15 ATT (33–51) 15 controls (38–48)	<ul style="list-style-type: none"> <li>• 3D – 7 cameras, Falcon (60 Hz)</li> <li>• Backless seat</li> <li>• Seat height: 105° shank height</li> <li>• Knee 85° flexion</li> <li>• Crossed arms</li> <li>• 5 trials</li> <li>• Self-selected speed</li> </ul>	<ul style="list-style-type: none"> <li>• Phase Ia: flexion only</li> <li>• Phase Ib: began when the force applied on the feet exceeded 30% of bodyweight</li> <li>• Phase II (momentum-transfer): between the instant when the force applied on the feet was 100% of bodyweight and the max <math>\Theta</math>ankle</li> <li>• Phase III: between max <math>\Theta</math>ankle and when <math>\Theta</math>trunk reached 5° of its value during stance</li> <li>• Angles compared with the initial seated value</li> <li>• Lumbar angle = L1 + L4</li> </ul>	Bilateral: <ul style="list-style-type: none"> <li>• greater trochanter</li> <li>• lateral knee epicondyle</li> <li>• L1, L4</li> <li>• midpoint of the sacral crest</li> </ul>
Burnfield (2012) [3] n = 10 (18–23)	<ul style="list-style-type: none"> <li>• 3D – 12 cameras, Qualisys (120 Hz)</li> <li>• Backless seat with adjustable height (45.72 cm/18 inches)</li> <li>• Relaxed arms</li> <li>• Number of trials not informed</li> <li>• Self-selected speed</li> </ul>	<ul style="list-style-type: none"> <li>• Complete STS movement</li> <li>• Pelvis angle: related to vertical plane</li> <li>• Hip compared with the thigh</li> </ul>	Unilateral (right side): <ul style="list-style-type: none"> <li>• greater trochanter</li> <li>• medial and lateral femoral condyles</li> </ul> Bilateral: <ul style="list-style-type: none"> <li>• acromion</li> <li>• iliac crests</li> <li>• ASIS/PSIS</li> </ul>



Johnson (2010) [21] <i>n</i> = 24 (mean: 26.5)	<ul style="list-style-type: none"> <li>• 3D – 6 cameras, Qualisys (100 Hz)</li> <li>• Backless seat: 85% knee height</li> <li>• Arms beside the body</li> <li>• Greater trochanters 4 cm from the seat edge</li> <li>• Face forward</li> <li>• Barefoot subjects; comfortable feet position marked with tape</li> <li>• 4 trials of 6 seconds</li> </ul>	<ul style="list-style-type: none"> <li>• Complete STS movement</li> <li>• Lumbar spine ROM in relation to the pelvis</li> <li>• Hip ROM in relation to the thigh</li> </ul>	Unilateral: <ul style="list-style-type: none"> <li>• lumbar</li> </ul> Bilateral: <ul style="list-style-type: none"> <li>• pelvis</li> <li>• thighs</li> </ul>
Johnson (2010) [22] <i>n</i> = 32 (mean: 27)	<ul style="list-style-type: none"> <li>• 3D – 6 cameras, Qualisys (100 Hz)</li> <li>• Backless seat: 100% knee height</li> <li>• 85° knee flexion</li> <li>• Greater trochanters 4 cm from the seat edge</li> <li>• Barefoot subjects</li> <li>• Feet position marked with tape</li> <li>• 5 trials of 6 seconds</li> </ul>	<ul style="list-style-type: none"> <li>• Complete STS movement</li> <li>• Lumbar spine ROM in relation to the pelvis</li> <li>• Hip ROM in relation to the thigh</li> </ul>	Unilateral: <ul style="list-style-type: none"> <li>• lumbar</li> </ul> Bilateral: <ul style="list-style-type: none"> <li>• pelvis</li> <li>• thighs</li> </ul>
Ikeda (1991) [23] <i>n</i> = 18 9 young (25–36) 9 elderly (61–74)	<ul style="list-style-type: none"> <li>• 3D – 4 cameras, Selspot II (150 Hz)</li> <li>• Backless seat: 80% knee height</li> <li>• Barefoot subjects</li> <li>• Feet 10.16 cm apart and parallel</li> <li>• Crossed arms</li> <li>• 2 trials</li> <li>• Speed of 52 bpm</li> </ul>	<ul style="list-style-type: none"> <li>• Phase I: began with hip or trunk flexion velocity</li> <li>• Phase II: began with seat-off of the buttocks</li> <li>• Phase III: began with maximal dorsiflexion and ended with hip extension velocity of 0</li> <li>• Phase IV: terminal hip extension</li> <li>• Hip: not explained</li> </ul>	Unilateral: <ul style="list-style-type: none"> <li>• trunk</li> </ul> Bilateral: <ul style="list-style-type: none"> <li>• pelvis</li> <li>• thighs</li> </ul>
Schenkman (1990) [24] <i>n</i> = 9 (25–36)	<ul style="list-style-type: none"> <li>• 3D – 4 cameras, Selspot II (153 Hz)</li> <li>• Backless seat: 80% of knee height</li> <li>• Barefoot subjects</li> <li>• Feet 10.16 cm apart</li> <li>• Crossed arms</li> <li>• 2 trials</li> <li>• Speed of 52 bpm</li> </ul>	<ul style="list-style-type: none"> <li>• Phase I: initiation of the movement</li> <li>• Phase II: seat-off</li> <li>• Phase III: began with maximum dorsiflexion</li> <li>• Phase IV: the hip ceased to extend</li> <li>• Hip: not explained</li> </ul>	Bilateral: <ul style="list-style-type: none"> <li>• legs</li> <li>• thighs</li> <li>• pelvis</li> <li>• trunk</li> </ul>
Anan (2015) [6] <i>n</i> = 17 (65–74)	<ul style="list-style-type: none"> <li>• 3D – 6 infrared cameras, Vicon (100 frames/s)</li> <li>• Backless seat</li> <li>• Vertical shanks</li> <li>• Crossed arms</li> <li>• Barefoot subjects</li> <li>• Feet apart (distance between ASIS)</li> <li>• Look forward instruction, no visual target</li> <li>• 5 trials</li> <li>• Self-selected speed</li> </ul>	<ul style="list-style-type: none"> <li>• Phase I: start to seat-off</li> <li>• Phase II: seat-off to the end of motion</li> <li>• Pelvic angle: relative to the global space</li> </ul>	Bilateral: <ul style="list-style-type: none"> <li>• acromion</li> <li>• inferior edge of the last rib</li> <li>• superior edge of the iliac crest</li> <li>• ASIS/PSIS</li> <li>• greater trochanter</li> <li>• lateral/medial epicondyle of the femur</li> </ul>
Kinoshita (2015) [25] <i>n</i> = 16 (21–43)	<ul style="list-style-type: none"> <li>• 3D – 7 cameras, Vicon (100 Hz)</li> <li>• 90° knee flexion</li> <li>• Crossed arms</li> <li>• 3 trials</li> <li>• Self-selected speed</li> </ul>	<ul style="list-style-type: none"> <li>• Complete STS movement</li> <li>• Hip angle: calculation not informed</li> <li>• Angles compared with the initial seated value</li> </ul>	Bilateral: <ul style="list-style-type: none"> <li>• mid-distance between the neck and the lateral aspect of the shoulder</li> <li>• ASIS/PSIS</li> <li>• 3 markers laterally on the thigh</li> </ul>
Kim (2014) [26] <i>n</i> = 16 (20–23)	<ul style="list-style-type: none"> <li>• 3D – 6 cameras, Vicon (100 Hz)</li> <li>• Backless seat height: distance from the mid-knee-joint line to the floor</li> <li>• 90° knee flexion</li> <li>• Crossed arms</li> <li>• 3 trials</li> <li>• 1-minute pause</li> </ul>	<ul style="list-style-type: none"> <li>• Complete STS movement</li> <li>• Pelvic angle: in relation to the ground</li> <li>• Lumbar angle: in relation to the pelvis</li> <li>• Hip angle: in relation to the pelvis</li> </ul>	Unilateral: <ul style="list-style-type: none"> <li>• T12, L1</li> </ul> Bilateral: <ul style="list-style-type: none"> <li>• ASIS/PSIS</li> <li>• lateral thigh</li> <li>• lateral malleoli</li> <li>• 3 cm to the left and to the right of L1</li> </ul>
Leardini (2011) [27] <i>n</i> = 10 (23–26)	<ul style="list-style-type: none"> <li>• 3D – 8 cameras, Vicon (100 Hz)</li> <li>• Backless seat height: tibia perpendicular to the floor</li> <li>• 90° flexion for hip and knees</li> <li>• Parallel feet</li> <li>• Relaxed arms</li> <li>• Number of trials not informed</li> <li>• Self-selected speed</li> </ul>	<ul style="list-style-type: none"> <li>• Complete STS movement</li> <li>• Joint angles compared with adjacent segments:</li> <li>• L1 in relation to L3</li> <li>• L3 in relation to L5</li> <li>• L5 in relation to the pelvis</li> </ul>	Unilateral: <ul style="list-style-type: none"> <li>• L1, L3, L5</li> </ul> Bilateral: <ul style="list-style-type: none"> <li>• acromion</li> <li>• suprasternal notch</li> <li>• ASIS/PSIS</li> <li>• xiphoid process</li> <li>• mid-point between the inferior angles of scapulae</li> </ul>
Park (2014) [28] <i>n</i> = 12 (20–27)	<ul style="list-style-type: none"> <li>• 3D – 8 cameras, Vicon (100 Hz)</li> <li>• 2 trials</li> <li>• Self-selected speed</li> <li>• 3-minute practice before trials</li> <li>• 1-minute rest prior to trials</li> </ul>	<ul style="list-style-type: none"> <li>• Complete STS movement</li> <li>• Pelvic angle: calculated as the difference between the maximal pelvic flexion angle and the initial pelvic angle</li> </ul>	Bilateral: <ul style="list-style-type: none"> <li>• ASIS/PSIS</li> <li>• lateral epicondyle of the femur</li> <li>• lateral thigh</li> </ul>

<sup>a</sup> Pelvic plane – the line joining PSIS to ASIS

ASIS – anterior superior iliac spine, ATT – Alexander Technique teachers, PSIS – posterior superior iliac spine,

ROM – range of motion, STS – sit-to-stand

Table 3. Protocols used to evaluate sit-to-stand and stand-to-sit movements (standing up from the sitting position and back to sitting) (indexed by video image analysis and by author)

1 <sup>st</sup> author (year) and sample (age range, years)	Video image analysis and performance parameters	Movement phases and description of angular measurement	Anatomical references markers
Kuo (2010) [5] <i>n</i> = 32 (60–75)	<ul style="list-style-type: none"> <li>• 2D – 1 camera, Peak system</li> <li>• Backless seat</li> <li>• 2 seat heights: 100% and 80% of knee height</li> <li>• Barefoot subjects</li> <li>• Foot position preferred by subject not changing during trials</li> <li>• Crossed arms</li> <li>• 3 trials</li> <li>• Only the ‘smoothest’ trial was analysed</li> <li>• Self-selected speed</li> </ul>	<ul style="list-style-type: none"> <li>• Start/end: the resultant linear velocity of the T1 marker greater or smaller than 1 cm/s</li> <li>• Seat-off: 10% increase of the normalized vertical displacement of the proximal thigh marker</li> <li>• Lumbar angle: angle between the line defined by T11–L1 and the line perpendicular to the pelvic plane<sup>a</sup></li> <li>• Hip angle: between the long axis of the femur (2/3 thigh–supracondylar markers) and the pelvic plane<sup>a</sup></li> </ul>	Unilateral (right side): <ul style="list-style-type: none"> <li>• L1, S2</li> <li>• T3 and T11 estimated during analysis</li> <li>• suprasternal notch</li> <li>• ASIS/PSIS</li> <li>• 2/3 thigh</li> <li>• 1/4 thigh</li> </ul>
Nuzik (1986) [29] <i>n</i> = 55 (20–48)	<ul style="list-style-type: none"> <li>• 2D – 1 Bolex camera (32 frames/s)</li> <li>• Backless seat height: 46 cm</li> <li>• Feet position: back/forward defined by the subject</li> <li>• Relaxed arms on thighs</li> <li>• 3 trials</li> <li>• Only one trial analysed according to criteria</li> <li>• Self-selected speed</li> </ul>	<ul style="list-style-type: none"> <li>• Sit-to-stand and back to sitting were analysed as a single movement</li> <li>• Pelvic angle: the line between the greater trochanter and the mid-iliac crest perpendicular to the horizontal plane</li> <li>• Hip angle: the lateral femoral epicondyle, the greater trochanter, and the mid-iliac crest</li> </ul>	Unilateral: <ul style="list-style-type: none"> <li>• acromion</li> <li>• mid-iliac crest</li> <li>• greater trochanter</li> <li>• lateral femoral epicondyle</li> </ul>

<sup>a</sup> Pelvic plane – the line joining PSIS to ASIS

ASIS – anterior superior iliac spine, PSIS – posterior superior iliac spine

or limb, as well as recording the key events of standing up and sitting down performance [32].

In relation to the seat attributes, all studies included in this review utilized a stool, that is, a structure without a backrest or armrest. A support for the upper limbs reduces the load over knees and hips and also decreases by 50% the moment of extension necessary to rise up from the sitting position [8]. Still, according to Janssen et al. [8], the backrest is a strategy to standardize the initial position of standing up. Such strategies condition the subject to a position that may differ from their habitual posture, so the authors assume that the movement will not represent the natural and reliable execution [8]. Concerning the seat height, to establish a fixed height means, for example, to increase hips and knees flexion of taller subjects in a way that the standing up movement becomes much more exigent or even impossible [8]. It is known that adjusting the seat from 115% to 65% of the knee height increases by almost 100% the angular speed of the trunk flexion in young adults to reach the stand position [33].

The position of the arms impacts on the displacement of the centre of mass because these segments move forward during motion [8]. For this reason, the study of the STS movement restricts the use of the arms

despite their being a common support for elderly and young adults [25, 34]. However, restricting the arms position considerably alters the angular displacement of the ankle, requiring more adjustments of this joint to reach the standing posture [7]. Also, the position of the feet influences the movement, as confirmed by Shepherd and Koh [35], who studied the positioning of the feet in the STS movement and showed that a posterior feet position reduced the total speed of movement and that an anterior positioning increased the time of the pre-extension phase. However, no electromyographic difference was found in the muscle groups of the lower limbs between the normal and posterior position of the feet [36].

In relation to the execution speed, subjects prevented from accomplishing the task in the self-selected speed in order to increase reproducibility may not act naturally, and so the execution will not be spontaneous or representative. The self-selected speed strategy seeks an execution closer to the habitual pattern and thus more reliable. Also, the number of trials for analysing the STS movement is diverse in literature, but the reliability (intraclass correlation coefficient of 0.67–0.94) and validity of 5 STS trials were confirmed and it is the most common number of repetitions applied [37].



Table 5. Joint angular values and ROM for the movements of sit-to-stand and stand-to-sit (mean ± SD)

ROM SAGITTAL PLANE, SIT-TO-STAND AND STAND-TO-SIT (°)			
Adults and elderly	Kuo [5] 100% knee	Kuo [5] 80% knee	
Lumbar spine	23.9 ± 6.9	33.4 ± 8.7	
Hip	101.2 ± 6.9	105.0 ± 8.7	
MAXIMAL AND MINIMAL JOINT ANGLES (°)			
Adults	Kuo [5] 100% knee	Kuo [5] 80% knee	
Lumbar	10.6 ± 7.2	20.3 ± 7.8	
Hip	99.5 ± 6.7	103.8 ± 6.5	
JOINT ANGLE AT MOVEMENT PHASES (°)			
Elderly		Kuo [5] 100% knee	Kuo [5] 80% knee
Lumbar	Start	1.5 ± 7.7	4.1 ± 7.9
Lumbar	Seat-off	9.0 ± 7.7	19.0 ± 8.4
Lumbar	End	-13.0 ± 7.9	-12.6 ± 7.5
Hip	Start	74.8 ± 5.8	86.0 ± 6.1
Hip	Seat-off	98.7 ± 6.8	102.8 ± 6.9
Hip	End	-1.8 ± 7.5	-1.1 ± 6.9
Adults		Nuzik [29]	
Pelvis	Start	116.25 ± 10.51	
Pelvis	End	88.58 ± 5.13	
Hip	Start	135.25 ± 11.55	
Hip	End	92.49 ± 3.65	

ROM – range of motion

Table 6. Studies scores of methodological quality appraisal in accordance with Downs and Black [16] scale

First author (year)	1	2	3	6	7	9	10	11	12	16	18	20	No. of √	Quality (%)	High quality
Standing up from the sitting position															
Anan (2008) [17]	√	√	√	√	√	√	x	x	x	√	√	√	9	75.0	Yes
Anan (2015) [6]	√	√	√	√	√	√	x	x	x	√	√	x	8	66.7	Yes
Burnfield (2012) [3]	√	√	√	√	√	√	x	x	x	√	√	x	8	66.7	Yes
Cacciatore (2011) [20]	√	√	√	√	√	√	√	x	x	√	√	x	9	75.0	Yes
Fotoohabadi (2010) [11]	√	√	√	√	√	√	√	x	x	√	√	√	10	83.3	Yes
Gilleard (2008) [19]	√	√	√	√	√	√	√	x	x	√	√	√	10	83.3	Yes
Ikeda (1991) [23]	√	√	√	√	√	√	x	x	x	√	x	x	7	58.3	No
Johnson (2010) [21]	√	√	√	√	√	√	√	x	x	√	√	x	9	75.0	Yes
Johnson (2010) [22]	√	√	√	√	√	√	√	x	x	√	√	x	9	75.0	Yes
Kinoshita (2015) [25]	√	√	√	√	√	√	√	x	x	√	√	√	10	83.3	Yes
Kim (2014) [26]	√	√	√	√	√	√	√	x	x	√	√	x	9	75.0	Yes
Leardini (2011) [27]	√	√	√	√	√	√	x	x	x	√	x	√	8	66.7	Yes
Park (2014) [28]	√	√	√	√	√	√	x	x	x	√	√	x	8	66.7	Yes
Schenkman (1990) [24]	√	√	√	√	√	√	x	x	x	√	√	x	8	66.7	Yes
Tully (2005) [18]	√	√	√	√	√	√	x	x	x	√	√	x	8	66.7	Yes
Stand-to-sit and sit-to-stand movements															
Kuo (2010) [5]	√	√	√	√	√	√	√	x	x	√	√	√	10	83.3	Yes
Nuzik (1986) [29]	√	√	√	x	√	√	x	x	x	√	x	x	6	50.0	No

(1) Is the objective and hypothesis of the study clearly described? (2) Are the main outcomes to be measured clearly described in the introduction or materials and methods section? (3) Are the characteristics of the subjects included in the study clearly described? (6) Are the main findings of the study clearly described? (7) Does the study provide estimates of the variability in the data for the main outcomes? (9) Are the characteristics of participants lost to follow-up described? (10) Are actual probability values reported for the main outcomes? (11) Were the subjects asked to participate in the study representative of the entire population from which they were recruited? (12) Were those subjects who were prepared to participate representative of the entire population from which they were recruited? (16) If any of the results of the study is based on 'data dredging,' is this made clear? (18) Were statistical tests used to assess the main outcomes appropriate? (20) Are the main outcome measures used accurate? Answers to the criteria: √ – yes, x – no.



Movement phases and description of angular measurement

Etnyre and Thomas [38], in their study on determining STS motion phases, suggest that there can be 6 vertical events (initiation of movement, counter-force prior to seat-off, the seat-off, the peak force, the post-peak rebound force, and the final steady standing force), 3 horizontal events (the start of force, the peak force, and the end of force), and 2 lateral events (right and left forces). Most of the studies in literature do not evaluate the transverse or frontal planes. So, the standardization of the phases or events of the movement is essential to establish parameters of comparison. Furthermore, it is important to mention that measuring speed and force requires more sophisticated evaluation tools, such as force plates, accelerometers, or force transducers. This technology, while sensitive to small changes in STS performance, is hardly available in clinical settings, besides making data analysis more complex [39].

Anatomical references markers

The anatomical landmarks diverge vastly and their positioning can bias the results. Kuo et al. [40], in their study on measurement errors due to skin movement,

compared the markers located on the thigh between the model that identified the major trochanter and lateral epicondyle of the femur and the model that calculated the position of the marker in 2/3 of the thigh and 1/4 of the thigh (the distance between the greater trochanter and the mid-lateral knee joint was measured along the mid-lateral thigh, and the 2/3 and 1/4 markers were positioned at the corresponding distances). Their main finding was that the trochanter-epicondyle model underestimated the sagittal angle of the hip, while the 2/3 proximal-1/4 distal thigh model provided a more accurate measurement of sagittal hip angle throughout the full available range of hip flexion. Skin movement on the pelvis had a small counterbalancing effect on the larger errors from lateral thigh markers, thereby decreasing hip angle error. Yet, Turcot et al. [41], to avoid the displacement of the markers on the skin, used rigid clusters with 3 markers on the thighs and legs. So, still there is no consensus over the landmarks utilized for the STS evaluation.

Angular values of normality

Meta-analyses have been performed to identify angular values of normality for the lumbar spine (Tables 7, 9, and 10) and hip (Tables 8, 11, and 12) for both

Table 7. Meta-analysis results for the lumbar spine range of motion (°) in relation to the pelvic plane in adult population (21–34 years)

Study	Sample size	Average or estimate	Standard error	Effect size and 95% CI		Weight (%)		Johnson [21]	Johnson [22]	Total (fixed effects)	Total (random effects)
				Lower limit	Upper limit	Fixed	Random				
Johnson [21]	24	24.80	2.29	20.31	29.28	38.35	45.71				
Johnson [22]	32	29.60	1.80	26.07	33.13	61.65	54.29				
Fixed	56	27.76	2.00	24.98	30.53	100.00	100.00				
Random	56	27.41	5.72	22.72	32.09	100.00	100.00				

Heterogeneity:  $Q = 2.72$ ;  $DF = 1$ ;  $p = 0.099$ ;  $I^2 = 63.21\%$

Table 8. Meta-analysis results for the hip range of motion (°) in relation to the thigh in adult population (21–34 years)

Study	Sample size	Average or estimate	Standard error	Effect size and 95% CI		Weight (%)		Johnson [21]	Johnson [22]	Total (fixed effects)	Total (random effects)
				Lower limit	Upper limit	Fixed	Random				
Johnson [21]	24	82.70	4.96	72.98	92.42	21.31	31.16				
Johnson [22]	32	89.60	2.58	84.54	94.66	78.69	68.84				
Fixed	56	88.13	2.29	83.64	92.60	100.00	100.00				
Random	56	87.45	3.20	81.19	93.71	100.00	100.00				

Heterogeneity:  $Q = 1.52$ ;  $DF = 1$ ;  $p = 0.217$ ;  $I^2 = 34.33\%$

Table 9. Meta-analysis results for the lumbar spine angle (°) at the start of the sit-to-stand movement in elderly population (60–75 years)

Study	Sample size	Average or estimate	Standard error	Effect size and 95% CI		Weight (%)		Fotoohabadi
				Lower limit	Upper limit	Fixed	Random	
Fotoohabadi [11]	24	2.7	1.37	0.01	5.39	49.52	49.52	
Kuo [5]	32	1.5	1.36	-1.17	-4.17	50.48	50.48	
Fixed	56	2.094	0.97	0.20	3.99	100.00	100.00	
Random	56	2.094	0.97	0.20	3.99	100.00	100.00	

Heterogeneity:  $Q = 0.39$ ;  $DF = 1$ ;  $p = 0.535$ ;  $I^2 = 0.00\%$

Table 10. Meta-analysis results for the lumbar spine angle (°) at the seat-off moment in elderly population (60–75 years)

Study	Sample size	Average or estimate	Standard error	Effect size and 95% CI		Weight (%)		Fotoohabadi
				Lower limit	Upper limit	Fixed	Random	
Fotoohabadi [11]	24	5.9	1.39	3.18	8.62	48.95	49.58	
Kuo [5]	32	9.0	1.36	6.33	11.67	51.05	50.42	
Fixed	56	7.48	0.97	5.58	9.39	100.00	100.00	
Random	56	7.46	1.55	4.43	10.50	100.00	100.00	

Heterogeneity:  $Q = 2.54$ ;  $DF = 1$ ;  $p = 0.111$ ;  $I^2 = 60.62\%$

Table 11. Meta-analysis results for the hip angle (°) at the start of the sit-to-stand movement in elderly population (60–75 years)

Study	Sample size	Average or estimate	Standard error	Effect size and 95% CI		Weight (%)		Fotoohabadi
				Lower limit	Upper limit	Fixed	Random	
Fotoohabadi [11]	24	77.1	1.28	74.59	79.61	39.03	44.42	
Kuo [5]	32	74.8	1.03	72.79	76.81	60.97	55.58	
Fixed	56	75.70	0.80	74.13	77.27	100.00	100.00	
Random	56	75.82	1.14	73.58	78.06	100.00	100.00	

Heterogeneity:  $Q = 1.97$ ;  $DF = 1$ ;  $p = 0.161$ ;  $I^2 = 49.12\%$

Table 12. Meta-analysis results for the hip angle (°) at the seat-off moment in elderly population (60–75 years)

Study	Sample size	Average or estimate	Standard error	Effect size and 95% CI		Weight (%)		Fotoohabadi
				Lower limit	Upper limit	Fixed	Random	
Fotoohabadi [11]	24	96.0	1.28	93.49	98.51	46.82	48.65	
Kuo [5]	32	98.7	1.20	96.34	101.06	53.18	51.35	
Fixed	56	97.44	0.88	95.72	99.15	100.00	100.00	
Random	56	97.39	1.35	94.74	100.03	100.00	100.00	

Heterogeneity:  $Q = 2.36$ ;  $DF = 1$ ;  $p = 0.124$ ;  $I^2 = 57.67\%$

adult and elderly population. The results allow to indicate the values of normality only for the ROM of the hip relative to the thigh (81.19–93.71°) in the adult population (Table 8). It was also possible to identify reference values for the elderly population only for the angular value of the hip in relation to the thigh (73.58–78.06°) and for the angular value of the lumbar spine in relation to the pelvic plane (0.20–3.99°), both at the exact initiation of the STS movement while in the seated position (Tables 11 and 9, respectively).

A limitation of this study is the absence of the evaluation of the coordination between the joints (lumbar, pelvis, and hip) in order to understand motor control and compensation mechanism. Therefore, this factor could be included in future research, similarly as the peripheral sensation and comfort sensation. For this purpose, further studies, especially comparative ones, could include the assessment of the subjective discomfort perception with scales such as the modified Schechter scale [42]. Also, populations with specific pathologies or injuries could be investigated.

## Conclusions

The STS assessment protocols diverge greatly from the location of anatomical markers to the positioning of the subject and the parameters of movement. In summary, it was possible to observe that most of the studies made use of video cameras with optoelectronic systems of 3-dimensional image analysis, in the range of 100–153 Hz, opting for backless seats with height adjustable to the extension of the individuals' legs. Also, in most of the studies, the subjects were asked to perform 3 repetitions of the movement at a self-selected speed, keeping the arms crossed. However, considering that this review presents a moderate quality of evidence, on the basis of the GRADE criteria, it is suggested that the parameters of the STS evaluation protocol be carefully defined by each researcher in accordance with their objectives.

Concerning the reference values for ROM and angular variables determined for the lumbar spine, pelvis, and hip with video analysis, it can be stated that for the adult population the normality values for the hip ROM, in relation to the thigh plane, vary between 81.19° and 93.71°. Also, at the very start of the STS movement, in the elderly population, the reference angular value of the lumbar spine relative to the pelvic plane varies from 0.20° to 3.99°, while the reference angle of the hip relative to the thigh plane ranges from 73.58° and 78.06°. Nevertheless, considering the heterogeneity of the included studies, it is possible

that further research may change the results for the angular values of normality found for the STS movement.

## Disclosure statement

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## Conflict of interest

The authors state no conflict of interest.

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