



## Review

# A standard operating procedure for the evaluation of vertical jumps performance through surface electromyography assessment: A scoping review

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## ABSTRACT

**Introduction:** The Countermovement Jump (CMJ) and the Squat Jump (SJ) are widely adopted tests to assess muscle strength and power. Neuromuscular data of the jump performance could be provided by surface Electromyography (EMG). While from a biomechanical and technical point of view, there are articles that support the two vertical jumps, less is published regarding surface EMG and the jumps. The objective of the present study was to review the literature to better understand the protocols adopted for a surface EMG evaluation during the CMJ and the SJ and eventually to propose a Standard Operating Procedure (SOP). A SOP could be a useful tool to better understand, compare, and interpret the findings.

**Methods:** A scoping review was performed. Data were collected on PubMed, Web of Science, and Scopus till 20<sup>th</sup> December 2024. The articles were screened against the eligibility criteria and narratively discussed.

**Results:** A total of 54 articles met the eligibility criteria. The articles present important differences in the methodology and the procedures followed. Differences were also detected in the hardware and the data analysis. From the common information of the articles, a SOP was proposed.

**Conclusions:** Different methodologies were adopted to evaluate neuromuscular function during the CMJ and the SJ tests. This makes difficult to compare the data. A SOP was proposed with information and guidelines related to muscles, hardware, and data processing. In this way, future studies could follow similar protocols increasing the possibility to compare the findings.

## 1. Introduction

Tests that evaluate the power and strength of the lower limbs are the vertical jumps (Liebermann and Katz, 2003, DUTHIE, 2006). Two valid, reliable, and widely adopted vertical jump tests are the Countermovement Jump (CMJ) and Squat Jump (SJ) (Markovic et al., 2004, SARGENT, 1924, Bosco and Viitasalo, 1982) tests. The CMJ is characterized by a countermovement before the toe-off phase, starting from the standing position (Bobbert et al., 1996), it is ideal to evaluate the reactive strength and the elastic component of the lower limbs (YOUNG, 1995). The SJ starts from a semi-squat position and mainly provides

power data for the lower limb muscles (YOUNG, 1995, Anderson and Pandy, 1993). Both jumps can be proposed as field tests, indeed they are easier to conduct, cheap, and require a few minutes to be administered (HEYWARD, 1991). This kind of evaluation is ideal in population-based studies, such as in the school (Artero et al., 2011) or sports setting (Younes-Egana et al., 2023, Stojanović et al., 2017, Slimani and Nikolaidis, 2019). Vertical jumps monitor the efficacy of injury recovery programs such as after the anterior cruciate ligament reconstruction (Dutaillis et al., 2024). These tests also assess the neuromuscular system (Claudino et al., 2017) with particular interest in the aspects related to fatigue (Alba-Jiménez et al., 2022). A recent systematic review proposed

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a Standard Operating Procedure (SOP) for the execution of SJ and CMJ test procedures (Petrigna et al., 2019). A SOP wants to make the protocol replicable by describing it step by step (Angiuoli et al., 2008, Tuck et al., 2009). In different fields, SOPs are already used increasing the quality of the research (Angiuoli et al., 2008), and a recent review highlighted its need too the sports science field (Petrigna et al., 2022). From a clinical and functional point of view, a SOP allows the comparison of protocols and their findings (Petrigna et al., 2022). This could increase the quality of the research in this field, facilitating the interpretation and making the research more homogeneous. By reducing the variables, it will be easier to interpret the data in the most effective and precise way.

The systematic review with a SOP for the CMJ and SJ test (Petrigna et al., 2019) described the protocol in terms of phases and biomechanical aspects. But, during the jump performance, other non-kinematic parameters have to be considered. The SJ is a purely concentric exercise characterized by no facilitating mechanisms (Hasson et al., 2004). Differently, during the countermovement, there is a storage of elastic energy and a larger motor unit activation (Asmussen and Bonde-Petersen, 1974). The elastic energy created by the tendinous structures during the pre-stretch and it is related to tendon stiffness (Kubo et al., 2007). This depends on genetic factors (Freitas et al., 2018) as well as the angular velocity of the joint during the push-off phase (Kurokawa et al., 2001). There is a higher neuromuscular activation in the concentric phase of the CMJ, if compared with the SJ, due to the stretch-shortening cycle (Bobbert and Casius, 2005, Bosco et al., 1982). Elevated electromyographic (EMG) signals mean elevated muscle force generation and higher jumps (Bosco et al., 1982). According to the literature, in ballistic or rapid voluntary movements, the neuromuscular system has an important role in the performance. There is in the agonistic muscles a decrement in H-reflex amplitude with no change in  $\alpha$ -motoneuron activity followed by a reduction of the EMG signal, improving motor unit synchrony (Aoki et al., 2002, Moritani and Shibata, 1994). This phenomenon is called the premovement silence period, it increases the muscular force and it seems to happen because the motoneurons are in a nonrefractory state (Mortimer et al., 1987). This highlights the necessity to study the jump performance also from a neuromotor point of view. It would allow a better understanding of the limits, potentiality, and capabilities of the neuromuscular system during these tests. All these aspects make EMG data useful for clinical decision-making, especially for those aspects that are not visible from a kinematic point of view.

Surface EMG is a non-invasive evaluation useful to detect the electric potential generated by the muscle fibers on the skin (ZAJAC, 1989). In recent years the development of EMG instruments is making them portable and lighter, accurate, and valid. The electrodes are becoming smaller and easier to apply to the human body (Spanu et al., 2021). This is bringing to an interest of the scientific community or of experts that work directly in the field. The EMG can identify the fiber type composition, and the muscle fiber cross-sectional area (Kupa et al., 1995). This is useful for studying the relationship between force and EMG signal (Luca, 1997) or fatigue in terms of neuromuscular expression (Häkkinen and Komi, 1983, Campanini et al., 2022, Luca, 1997). This allows the study of movement and muscle function as well as neural strategies (Campanini et al., 2022, Farina et al., 2014). This test examines the timing of muscle contraction (Luca, 1997), the temporal characteristics of an action (Rodacki et al., 2002), and muscle coactivation (Woods et al., 2023). Despite this technology is becoming user-friendly, its use is not easy (Campanini et al., 2022). The complexity of the electrode placement, data analysis, and interpretation requires a deeper study and understanding (Campanini et al., 2022). To help the community in the correct use of EMG and electrode application, guidelines were proposed by the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) group (Hermens and Freriks, 1997).

The combination of CMJ or SJ and surface EMG allows a better understanding of the neuromuscular system. This combination is widely adopted in the literature. This is probably because the two vertical

jumps, as previously highlighted, can provide useful information about muscle power and coordination and can be easily proposed in different contests and populations. The addition of an EMG evaluation allows for a more complete and precise vision, also considering the neuromuscular system. In this way, the vertical jumps became a potentially useful tool for example for rehabilitation monitoring or return-to-sport after injury (Labban et al., 2024), neuromuscular fatigue and readiness analysis (Watkins et al., 2017), to study muscle asymmetries (Fox et al., 2023) or executive functions (Scharfen and Memmert, 2021). Therefore, it is interesting to understand if the methodology chosen by the authors is replicable and if the guidelines provided by the literature are followed. Indeed, a lack of consistency in the methodology makes the interpretation of the results difficult (Petrigna et al., 2022). Being able to control the variables allows researchers to arrive at cause-effect conclusions more confidently. Uncontrolled variables and bias could lower the quality of a study and make the results unclear (Grimes and Schulz, 2002). Furthermore, in recent years, thanks also to the advent of new technologies and artificial intelligence also in the physical rehabilitation field (Sumner et al., 2023), open-source platforms and deep network modules are becoming a reality for EMG signals (Ma et al., 2024, Mullins and Hanlon, 2016). It becomes essential to be as consistent and precise as possible in the methodology adopted to make this process valid and reliable. The objective of the present study will be to analyze the current literature, published in the last 20 years, studying the methodology adopted in the evaluation, through the surface EMG, of the SJ and the CMJ performance. Our attention will be on the electrodes adopted, the procedure followed, the normalization of the data, and in the jump phase identification. Eventually, if a standardized methodology is not followed, the second objective of the present study is to analyze the protocols adopted in the studies included and to propose a SOP.

## 2. Materials and methods

Due to the objective focused on extrapolating a protocol for data collection with surface EMG, it was decided to perform a scoping review since the quality of the intervention protocols does not influence the findings. The review is not about the study of the effect of an intervention but with the desire to propose methodological considerations. Before the data collection, the methodology was written and it was followed step by step during the article collection and selection process. The review follows the preferred reporting items for systematic reviews and meta-analyses for Scoping Reviews (PRISMA-ScR) checklist and explanation (Tricco et al., 2018).

### 2.1. Eligibility criteria

Following the PRISMA checklist, parameters for population, intervention, comparison, outcomes, and study design (PICOS) were adopted. The study sample was composed of healthy human adults. Studies that were about adolescents or younger participants, elderly (over 65 years of age), people with disability (physical or mental), or about injuries were excluded. The intervention and the term of comparison proposed were not investigated because the review wants to evaluate the EMG protocols and not an effect. The outcomes of interest were about the surface EMG protocols adopted to evaluate muscle performance during a CMJ or a SJ test. Studies that used surface EMG to evaluate the upper and lower, or trunk were included. Only manuscripts published in the last twenty years (after 2004) were included. Data had to be original and directly adopted during the vertical jump procedure, models were excluded. The study design of the study had to be original, indeed, reviews with or without meta-analysis, abstracts, editorials, books, letters, opinions, citations, conference abstracts, or book reviews were excluded. Manuscripts were also excluded if they were not peer-reviewed. Observational studies, descriptive studies, clinical trials, randomization, and longitudinal were included only if written in English.

2.2. Data collection process

The electronic databases PubMed (NLM), Web of Science (TS), and Scopus were searched. All manuscripts detected up to the 20<sup>th</sup> of December 2024 were downloaded as citations and were considered for the selection process.

Two following keyword groups were created:

Keywords 1: EMG, electromyography;

Keywords 2: vertical jump, CMJ, countermovement jump, SJ, squat jump.

The two keywords' groups were matched with the Boolean operators AND and OR.

The following string was created and adopted, with differences in terms of quotation marks according to the electronic database characteristic, on PubMed, Web of Science, and Scopus:

(EMG OR electromyography) AND (vertical jump OR CMJ OR countermovement jump OR SJ OR squat jump).

2.3. Record, management, and analysis of the manuscript

All citations collected were uploaded on EndNote software (EndNote version X8; Thompson Reuters, NY, USA), and a specific folder was created to manage all articles. Before proceeding with the selection process, duplicates were automatically removed through a function of EndNote. The remaining articles were screened by two investigators who worked independently. In case of disagreement, the coordinator of the study was involved and a final decision was taken by him.

A three-step procedure was followed to select our articles. First, a selection by title was executed. Keywords and an article-by-article selection were performed by reading the titles on EndNote software. In the

second step, the manuscripts were searched on the web and a selection by abstract was performed. In the last step, the manuscripts were downloaded and the eligibility criteria were applied to the full-text.

After the screening process, the most important data within each article were collected in a Microsoft Excel (Microsoft Corp, Redmond, Washington) spreadsheet. The information collected included: the 1<sup>st</sup> author and year of publication of the manuscript; number of participants, muscles studied; electrode characteristics and placing; skin preparation; information about the instrument; information about the data collected; information related to the protocol to collect the data; information about the jump analysis.

In the last phase, all data were descriptively analyzed. The most recurrent data were adopted to create the SOP and its validity and meaning were studied through the recent literature.

3. Results

A total of 2817 manuscripts were detected on the three electronic databases (PubMed: 802; Web of Science: 1656; Scopus: 359 manuscripts) searched. After duplicate removal, 2297 manuscripts remained to be screened against the eligibility criteria.

During the screening process articles were excluded in the 3 steps and a final number of 54 articles was included for analysis. The PRISMA diagram flow synthesizes the manuscript selection process (Fig. 1).

A total of 1095 participants was included in the studies with a mean of 20 participants for the study. The minimum number of participants was 5 (AKL, 2013, Kopper et al., 2013), and the maximum number was 64 (Rubio-Arias et al., 2017) participants. A total of 33 studies (61 %) used only the CMJ, 7 studies (13 %) only the SJ, and 14 studies (26 %) adopted both jumps.

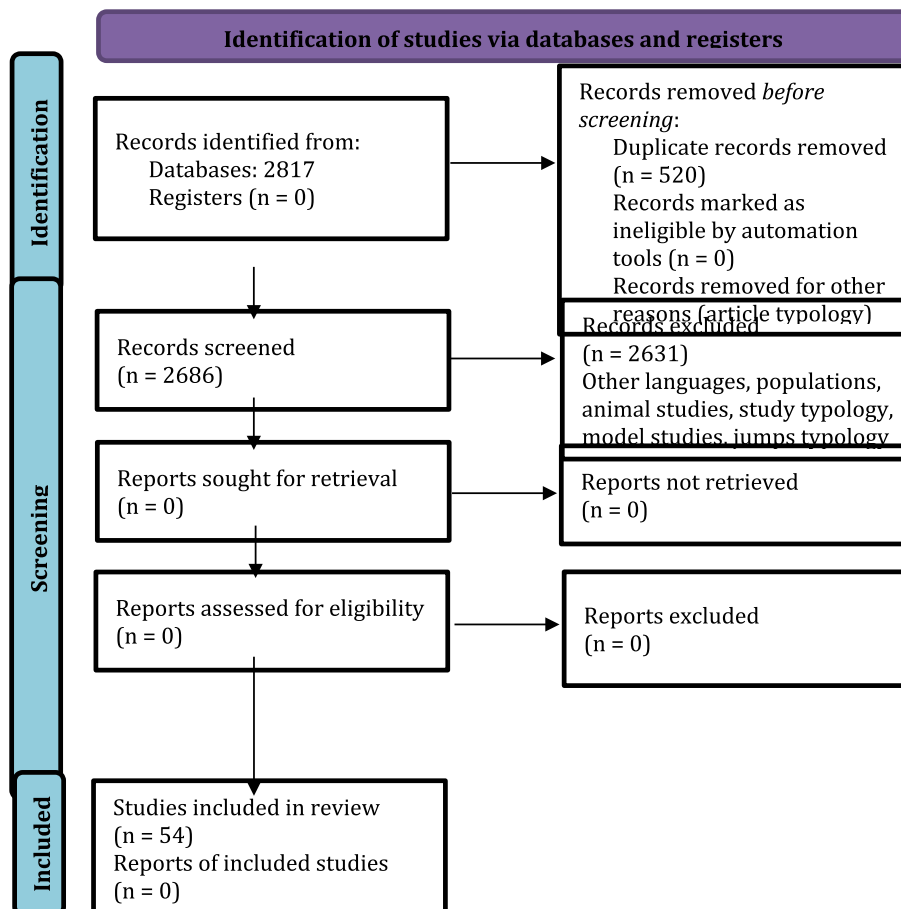


Fig. 1. PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only.

### 3.1. Muscles investigated

The most studied muscle was the vastus lateralis (n. of studies: 37). Widely investigated were also biceps femoris (n. of studies: 31), gastrocnemius medialis (n. of studies: 19), rectus femoris (n. of studies: 21), vastus medialis (n. of studies: 18), tibialis anterior (n. of studies: 15), gastrocnemius lateralis (n. of studies: 11), semi-tendinous, and gluteus maximus and soleus (n. of studies: 9). Less studied muscles were the gluteus medius, medial hamstring (semimembranosus and semitendinosus), and peroneus longus (n. of studies: 3), lateral hamstring, rectus abdominis, external oblique, gastrocnemius, erector spinae, and adductor longus (2 times respectively). Only 1 article studied the anterior and posterior deltoid, biceps brachii, triceps brachii, latissimus dorsi, and internal oblique.

Most of the studies evaluated 2 (n. of studies: 11) or 3 muscles (n. of studies: 10). Four muscles were studied in 8 articles, and 1 muscle in 7 studies. Five muscles were studied in 6 studies and 6 muscles in 5 studies. Eight muscles and 7 muscles in 2 studies, and 10 (Falch et al., 2020) or 13 (Charoenpanich et al., 2013) muscles in 1 study respectively. The articles that evaluated only 1 muscle, studied the vastus lateralis in 4 studies, the rectus femoris, biceps femoris, and gastrocnemius lateralis in 1 study respectively. When 2 muscles were studied, the combination vastus lateralis-biceps femoris was the most adopted (n. of studies: 3). Other combinations were adopted one time. The gastrocnemius medialis was associated with vastus lateralis, biceps femoris, tibialis anterior, and rectus femoris. Vastus lateralis and vastus medialis, and lateral hamstring and medial hamstring were studied together. When three muscles were studied together, the combination of vastus lateralis, vastus medialis, and biceps femoris was adopted two times. Vastus lateralis and vastus medialis were studied also with rectus femoris, gluteus maximus, and gastrocnemius medialis. Other combinations for the vastus lateralis were with rectus femoris and biceps femoris, gastrocnemius medialis and gluteus maximus, gastrocnemius lateralis, and gastrocnemius medialis. Other combinations less adopted were rectus femoris, biceps femoris, adductor longus, rectus femoris, biceps femoris, semi-tendinous, and vastus medialis, medial hamstring, and biceps femoris.

### 3.2. Electrodes characteristics and placement

A total of 29 studies adopted the silver-silver chloride electrodes (Ag-AgCl). Four authors did not provide information about the electrodes. Most of the studies provided general information with words such as “bipolar” or “surface electrodes” or “adhesive electrodes”. Other and more detailed information is presented in Table 1.

Regarding the dimension, most of the studies adopted a 10 mm diameter (n. of studies: 6). The 8-, 11- and 13-mm diameter was adopted in 2 studies respectively. Less adopted diameters were 5, 20, 22, 24, and 50 mm. Seven studies specified to adopt of disc, round, or circular electrodes. The interelectrode distance was mainly 2 cm (n. of studies: 11), 2.5 cm, or 1 cm (n. of studies: 2). One study adopted 2.2 cm. A total of 14 studies applied the electrodes on the dominant leg, 12 studies on the right leg, and 6 studies on both legs.

Regarding the placement of the electrodes, most of the authors followed SENIAM guidelines. 11 studies adopted the protocol of 2000 (Hermens et al., 2000), 7 studies adopted the protocol of 1999 (Hermens et al., 1999), and 5 studies took the information from the website. Some studies (n. of studies: 5) reported that they followed SENIAM guidelines but did not report the bibliographic source. One study adopted the protocol SENIAM of the 1997 (Hermens and Freriks, 1997). Seven studies adopted previously published protocols (Goodwin et al., 1999, Merletti and Parker, 2004, Kasman et al., 1998, Cram et al., 1998, Pereira et al., 2009, PEROTTO, 2011, Clarys and Cabri, 1993) or DELSYS™ guidelines (Inc., 2012). For the studies that adopted their protocols, they wrote general information. The sentence in which the electrode was placed on the muscle belly of each muscle was adopted

several times (n. of studies: 9). Some studies were more detailed such as that the electrode was distal to the motor point and parallel to the direction of the muscle fibers (n. of studies: 4). Three studies offered more detailed protocols and they are provided in Table 1.

A total of 15 studies provided information and adopted the reference electrodes. The patella was adopted 3 times and the tibia 4 times respectively. Two studies adopted the proximal head of the fibula. The styloid apophysis, left wrist, the bony surface of the contralateral wrist; the right ulnar styloid process, the right ankle in a line with the lateral malleolus, the clavicle bone prominence, and the C-7 vertebral prominence were adopted one time respectively.

Regarding the skin treatment, the combination of shaving, abrading, and rubbing was the most adopted (n. of studies: 21). It was followed by shaving and rubbing (n. of studies: 10). Shaving and cleaning with alcohol and abrading and rubbing were adopted 4 times respectively. Shaving and abrading, cleaning, and DELSYS™ guidelines in one study respectively. A total of 12 studies did not report information in this regard.

### 3.3. Protocol characteristics

Most of the studies specified that they used wireless EMG (n. of studies: 44). The remaining studies did not provide information in this regard.

Some studies reported also the number of channels of the EMG. An 8-channel EMG was adopted in 9 studies. 8 studies adopted a 16-channel EMG. A 2-channel EMG was adopted in 2 studies. One study adopted the 4-channel EMG.

The sampling frequency ranged from 1,000 Hz to 4,800 Hz. Most of the studies sampled at 1,000 Hz (n. of studies: 25) or 2,000 Hz (n. of studies: 14). A frequency of 1500 Hz was adopted in 6 studies. Two studies adopted a frequency of 1,080 Hz. Less adopted frequencies were 1,200 Hz, 3,000 Hz, 4,000, and 4,800 Hz (1 time each).

During data processing, the bandwidth and the bandpass ranged from 1.5 Hz to 10,000 Hz. The most adopted band ranged from 10 to 500 Hz (n. of studies: 10) and 20–500 Hz (n. of studies: 8). Band 20–450 Hz was adopted 4 times. Bands of 10–400 Hz and 10–450 Hz were adopted in 2 studies respectively. Other ranges adopted only one time are proposed in Table 2.

A total of 11 studies proposed the maximal voluntary isometric contraction. Similarly, the maximal voluntary contraction was proposed 10 times. The other studies performed other types of tests or normalized the data with other parameters. In the specific, some authors reported the protocol to determine the maximal voluntary isometric contraction.

The root mean square was adopted in 30 studies. 4 studies averaged the data. Median frequency and full-wave rectification were also adopted.

Most of the studies (n. of studies: 14) adopted the percentage of the maximal voluntary (isometric) contraction to normalize the value. Other interesting methodologies to normalize the data were associated with the jump performance. It was normalized with the maximal activation during the take-off / up-ward phase of the CMJ (n. of studies: 2), or the propulsion phase (n. of studies: 2); to mean concentric phase at 6 5 % system maximal mass; to mean values recorded in the preferred countermovement; to the highest root mean square value obtained in the ascending phase (1 study respectively). Other normalization techniques adopted the EMG recorded before or at rest, during pre-activation (n. of studies: 5), or considering the maximal values (n. of studies: 2).

Most of the studies (n. of studies: 30) evaluated the jump phases through force platforms, exploiting the ground reaction forces. The force platform was also associated with other instruments such as the motion capture system (n. of studies: 10), and ultrasound probes (n. of studies: 1). Widely adopted was also the motion capture system (n. of studies: 11). Less adopted instruments were inertial sensor (n. of studies: 2), linear encoder and force sensor and goniometer and linear transducer data (1 study respectively).

**Table 1**  
Summary of the electrode's characteristics and placement in the included studies.

1 <sup>st</sup> author, year	Main objective and how sEMG was adopted	N.	Jump	Muscles	Type of electrodes	Electrodes placing	Skin preparation
Affi 2012 (Affi and Hinrichs, 2012)	Compare the mechanism of landing	18	CMJ	GL, MH, LH, VM, VL	Differential surface electrodes, Ag–AgCl; diameter: 0.8 cm	Protocol (Perotto, 2011); ID: 2.2 cm; RE on the right ulnar styloid process	Shaving, abrading, rubbing
Akl 2013 (Akl, 2013)	Compare biomechanical parameters and muscle activity	5	CMJ, SJ	GMx BF, RF, VL, VM, GL, Sol, TA	Bipolar, Ag/AgCl surface electrodes	ID: 2 cm	Shaving, abrading, rubbing
Anbarian 2022 (Anbarian and Avazzadeh Samani, 2022)	Study the effects of traditional and post-activation potential warm-ups methods on EMG variables	14	SJ	RF, VL, VM, BF, ST, GM, TA	Ag/AgCl with a diameter of 1 cm in a dipole array	SENIAM guidelines (Hermens et al., 2000)	Shaving and cleaning with alcohol
Arabatzis 2010 (Arabatzis et al., 2010)	sEMG adopted to study biomechanical adaptation to different training modalities	36	SJ, CMJ	RF, GM	Bipolar surface electrodes in the form of metallic bars	ID: 1 cm	Shaving and cleaning with alcohol
Bond 2017 (Bond et al., 2017)	Study asymmetries and examine nervous activation of lower limbs	24	CMJ	VL, BF	Silver–silver chloride electrodes	BL. SENIAM guidelines (from the website); RE on the proximal head of the fibula	Shaving, abrading, rubbing
Charoenpanich 2013 (Charoenpanich et al., 2013)	Study the major muscles used during vertical jumps	20	SJ	DA, DP, BB, TB, LD, ES, RA, VM, RF, BF, ST, TA, GM	No Info	RL	Shaving and cleaning
Clark 2020 (Clark et al., 2020)	Study how back squat strength affect trunk activation	50	SJ, CM	lumbar sacral ES, upper lumbar ES, RA, EO	Two adhesive electrodes	RL. SENIAM guidelines (Hermens et al., 2000).	Shaving, abrading, rubbing
Cormie 2006 (Cormie et al., 2006)	Study the effect of whole-body vibration on CMJ performance	9	CMJ	VL, VM, BF	Surface electrode (1-cm circular conductive area)	Over the belly of each measured muscle, distal to the motor point and parallel to the direction of the muscle fibers; ID: 2 cm	No Info
Donahue 2019 (Donahue et al., 2019)	Study the effect of hydration state on sEMG	20	CMJ, SJ	VL, VM, ST, GM,	Bipolar silver/silver chloride surface electrodes	DL. SENIAM guidelines (Hermens et al., 1999); RE on the tibial tuberosity	Abrading and rubbing
Earp 2016 (Earp et al., 2016)	Compare sEMG during different exercises	10	SJ	VL	Self-adhesive surface electrodes with 0.5 cm diameter.	RL. SENIAM guidelines (Hermens and Freriks, 1997); ID: 2.5 cm	Shaving, abrading, rubbing
Falch 2020 (Falch et al., 2020)	Study muscle activity in different exercise	21	CMJ	VL, VM, RF, AL, BF, ST, Sol, GL, GMed, GMx	Electrodes 1.1 cm contact diameter and	DL. SENIAM guidelines (Hermens et al., 2000)	Shaving and rubbing
Fletcher 2010 (Fletcher, 2010)	Study the effect of different dynamic stretch velocities	24	CMJ	Gastrocnemius, TA, BF, VL	SX230 surface pre-amplified (1 k) electrodes	DL. Protocol (Clarys and Cabri, 1993); RE on the right ankle in a line with the lateral malleolus	Shaving and rubbing
Fukutani 2014 (Fukutani et al., 2014)	Study the magnitude of post action potential according to the intensity of a squat exercise	8	CMJ	RF, VL, BF, GMx	Bipolar electrodes Ag/AgCl, diameter: 1.1 cm	RL. Placed on the muscle belly of each muscle, ID: 2 cm; RE on the patella	Abrading and rubbing
Gheller 2014 (Gheller et al., 2014)	Study the CMJ with biomechanical parameters	22	CMJ	VL, RF, BF	Surface electrodes AgCL3 in bipolar configuration	SENIAM guidelines (Hermens et al., 2000); RE on the anterior surface of the tibia	
Giroux 2015 (Giroux et al., 2015)	Study lower limb muscle coordination with loading	20	SJ	SOL, ST, GL, TA, VL, RF, GMx	The bipolar, silver/silver chloride, surface disc electrodes	SENIAM guidelines	Shaving, abrading, rubbing
Harry 2015 (Harry et al., 2015)	Effect of footwear on EMG activity	15	CMJ	BF, GM, PL, ST / SM, SOL, TA, VL, VM	2-cm round Ag/AgCl	DL. SENIAM guidelines (Hermens et al., 1999); RE on the anterior aspect of the patella	Shaving, abrading, rubbing
Henderson 2019 (Henderson et al., 2019)	Determine the effect of ankle braces on lower limbs EMG	42	CMJ	GL, PL, BF, RF, GMed.	No Info	DL. DELSYS™ guidelines (Inc., 2012)	DELSYS™ guidelines
Hollville 2020 (Hollville et al., 2020)	Study the effect of different surfaces on EMG	16	CMJ	GM, VL	Bipolar electrodes	Placed longitudinally concerning the fascicle's alignment and the ultrasound position	No Info
Howard 2015 (Howard et al., 2015)	Study the effect of fatigue on stable and unstable surface	14	CMJ	VM, BF, GM, TA, EO, internal oblique, lower and upper ES	Circular bipolar surface electrodes. Foam electrodes, diameter: 1.3 cm	DL. SENIAM guidelines (Hermens et al., 1999)	Shaving, abrading, rubbing
Jakobsen 2012 (Jakobsen et al., 2012)	Study the effect of training during stretch–shortening cycle	49	CMJ	VL, VM, RF, BF, ST, GL	Bipolar EMG-electrodes	DL. The medial portion of the VL, VM, RF, BF, ST, and the belly of GL. RE: anterior tibial crest; ID: 2 cm	Shaving and rubbing
Jankaew 2024 (Jankaew et al., 2024)	Study hamstring activation	40	CMJ	LH, MH	Surface EMG electrodes	DL. The middle of the muscle belly, the midpoint between the origin and the insertion points of the H.	Cleaning
Kannas 2015 (Kannas et al., 2015)	Study the effects of detraining after a plyometric training	20	SJ, CMJ	GM, TA	Two bipolar silver chloride surface electrodes	Muscle bellies; ID: 2 cm	No Info

(continued on next page)

Table 1 (continued)

1 <sup>st</sup> author, year	Main objective and how sEMG was adopted	N.	Jump	Muscles	Type of electrodes	Electrodes placing	Skin preparation
Kopper 2012 (Kopper et al., 2013)	Study the muscle activation and pretension in jumps	5	CMJ, SJ	VL	Bipolar, circular; diameter: 1 cm; silver-silver chloride electrodes	SENIAM guidelines (from the website)	Shaving, abrading, rubbing
Kovacs 2023 (Kovács et al., 2023)	Examine the effect of arm swing on EMG activity	16	SJ, CMJ	GM, GL, SOL, VL, RF, BF	Silver-silver chloride bipolar electrodes (1 cm diameter)	SENIAM guidelines (Hermens et al., 2000); RE on the ipsilateral patella; EMG cables taped over the skin	Shaving, abrading, rubbing
Kowal 2022 (Kowal et al., 2022)	Study the impact of whole-body cryotherapy	24	CMJ	RF	Self-adhesive silver-silver chloride electrodes Ag/AgCl	DL. SENIAM guidelines	Shaving and cleaned
Lamas 2012 (Lamas et al., 2012)	Study the effects of training on neuromuscular adaptation	40	CMJ, SJ	VL, VM	Ag/AgCl circular electrode pairs	Protocol (Pereira et al., 2009); RE on the medial shaft of the tibia; ID: 2 cm	Shaving, abrading, rubbing
Lazaridis 2013 (Lazaridis et al., 2013)	Study the biomechanical differences	24	SJ, CMJ	VL, BF, GM, SOL, TA	Bipolar surface Ag/AgCl electrodes, contact surface 0.8 cm	DL. RE on the bony surface of the contralateral wrist; ID: 2 cm	Shaving and rubbing
Leporace 2011 (Leporace et al., 2011)	Study myoelectric activity in single and double leg landing	15	CMJ	RF, BF AL/gracilis	Ag/AgCl electrodes	Protocol (Cram et al., 1998). ID: 2 cm; the electrode cables were fixed to the skin using adhesive tape	Shaving and rubbing
Lesinski 2016 (Lesinski et al., 2016)	Examine the effects of fatigue and surface instability	20	CMJ	VM, VL, BF, TA, GM, SOL	Circular bipolar surface electrodes Ag/AgCl, diameter: 1.3 cm	SENIAM guidelines (Hermens et al., 1999); RE on the tibial bone, elastic bands, tapes and transparent films fixed electrodes, cables	Shaving, abrading, rubbing
Lowell 2024 (Lowell et al., 2024)	Study reaction times	17	CMJ	TA, GM, VL, BF	Pre-gelled electrodes Ag/AgCl	RL. SENIAM guidelines (Hermens et al., 2000)	Shaving and rubbing
Mackala 2013 (Mackala et al., 2013)	Investigate the jump according foot placement	6	SJ, CMJ	gastrocnemius, VM, GMax, RF, TA, BF,	Bipolar surface electrodes Ag-AgCl	BL. Belly of each muscle, parallel to the muscle fiber direction	No Info
Mackenzie 2014 (MacKenzie et al., 2014)	Study muscle activation patterns	10	SJ	GM, VL, RF, BF, GMed	Surface electrode	RL. SENIAM guidelines (from the website)	No Info
Maixnerová 2019 (Maixnerová et al., 2019)	Examine the reliability of electromechanical delay	13	SJ	RF, BF, ST	Self-adhesive, disposable 2.4 cm electrodes	DL. Protocol (Merletti and Parker, 2004); ID: 1 cm	No Info
Marchetti 2014 (Marchetti et al., 2014)	Study fatigue	10	CMJ	VL	Ag/AgCl round self-adhesive passive electrodes, 1 cm diameter	BL. SENIAM guidelines; RE on the clavicle bone prominence	Shaving and abrading
Marquez 2017 (Márquez et al., 2017)	Study the CMJ from a kinetic and EMG activation	20	CMJ	GM, TA, VL, RF, RF, BF	Pre-gelled bipolar surface Ag-AgCl electrodes	RL. SENIAM guidelines (Hermens et al., 2000)	No Info
Marquez 2009 (Marquez et al., 2009)	Study how pedaling performance affect vertical jumps	10	CMJ	VL, BF, GM, Sol	Ag-AgCl bipolar surface electrodes.	RL. The electrodes were coated with electrolytic gel, over the middle of the muscle belly along the longitudinal axis; RE on the styloid apophysis, left wrist	Shaving, abrading, rubbing
Masci 2010 (Masci et al., 2010)	Study specific adaptations in EMG and biomechanics	14	SJ, CMJ	VL, BF	Round silver surface electrodes	BL. SENIAM guidelines (Hermens et al., 2000); RE on the knee.	Abrading and rubbing
McBride 2008 (McBride et al., 2008)	Observe pre-activity and eccentric muscle activity in different jump types	8	SJ, CMJ	VL, VM, BF	A disposable surface electrode (1 cm circular conductive area)	DL. Over the belly of the muscle, distal to the motor point, and parallel to the direction of muscle fibers; ID: 2 cm	No Info
McHugh 2024 (McHugh et al., 2024)	Examine how the depths of CMJ influence muscle activation	10	CMJ	GMx, VL, GM	Ag/AgCl passive dual electrodes	Center of the muscle belly; personal protocol; ID 2 cm	Shaving, abrading, rubbing
McKinlay 2017 (McKinlay et al., 2017)	Study the neuromuscular activation with jump parameters	41	CMJ, SJ	VL	Bipolar surface electrode	RL. SENIAM guidelines; RE over the C-7 vertebral prominence	Abrading, and rubbing
Mina 2018 (Mina et al., 2019)	Study the effects of different warm-up	15	CMJ	VL, VM, GMx	Bipolar adhesive surface electrodes Ag-AgCl	SENIAM guidelines	Shaving, abrading, rubbing
Montalvo 2021 (Montalvo et al., 2021)	Determine the effects of rest and training on jump performance	14	CMJ	RF, BF	The pre-gelled Ag-AgCl electrodes	Protocol (Goodwin et al., 1999)	Shaving, abrading, rubbing
Padulo 2013 (Padulo et al., 2013)	EMG of upper extremities in different jumps	12	CMJ, SJ	BF	Bipolar surface electrodes	SENIAM guidelines (Hermens et al., 2000); EMG cables were secured using elastic bands	Shaving and rubbing
Paschaleri 2024 (Paschaleri et al., 2024)	Investigate the effect of maturation on jumps	20	CMJ	MG, TA	No Info	SENIAM guidelines (from the website)	Shaving, abrading, rubbing

(continued on next page)

Table 1 (continued)

1 <sup>st</sup> author, year	Main objective and how sEMG was adopted	N.	Jump	Muscles	Type of electrodes	Electrodes placing	Skin preparation
Peng 2023 (Peng et al., 2024)	Explain the internal mechanism of attention	21	CMJ	VL, ST, TA, RF, GM	Bipolar EMG electrodes affixed using adhesive tape	DL. Placed on the center of each muscle belly; to fix: pressure-sensitive adhesive tape and cohesive bandages	Shaving, abrading, rubbing
Pinfold 2018 (Pinfold et al., 2018)	Study the effect of a protocol also on EMG	10	CMJ	BF, GM	Surface pre-gelled Ag-AgCl electrodes, 2.2 cm diameter	BL. SENIAM guidelines (Hermens et al., 2000)	Shaving, abrading, rubbing
Rubio-Arias 2017 (Rubio-Arias et al., 2017)	Analyze gender differences in neuromuscular behaviour	64	CMJ	GL, GM, VL	Bipolar Ag/AgCl surface electrodes.	BL. SENIAM guidelines (Hermens et al., 2000)	Shaving and rubbing
Russell 2007 (Russell et al., 2007)	Study muscle activation to further understand physical maturation	55	CMJ	VM, MH, BF	Silver/silver chloride pre-gelled surface electrodes	Placed 2.5 cm apart and parallel to the muscle fibers over the longitudinal midline between the motor point and the tendon; RE: over the head of the fibula	Shaving, abrading, rubbing
Salles 2011 (Salles et al., 2011)	Study differential effects of CMJ magnitude	10	CMJ	VL, GL, GMx, ES	No Info	SENIAM guidelines (Hermens et al., 1999)	No Info
Shi 2023 (Shi et al., 2023)	Compare the acute effect of different exercises	13	CMJ	VL, VM, MG	AgCl	DL. SENIAM guidelines (from the website)	Shaving, abrading, rubbing
Sotiropoulos 2010 (Sotiropoulos et al., 2010)	Determine the effects of warm-up	26	CMJ	RF, VL, VM	Bipolar silver surface electrodes, active area diameter 0.5 cm	RL. SENIAM guidelines (Hermens et al., 1999)	Shaving, rubbing
Wade 2020 (Wade et al., 2020)	Study the deep of the CM	12	CMJ	SOL, GL, VL, RFEM, BF, GMx	Bipolar	RL. SENIAM guidelines (Hermens et al., 1999)	No Info
Walker 2010 (Walker et al., 2010)	Assess acute neuromuscular and endocrine responses during different training	10	SJ	VL, BF	input impedance $\geq 100$ , common mode rejection ratio 80 dB, 1000 gain	RL. SENIAM guidelines	No Info
Wallmann 2008 (Wallmann et al., 2008)	Study the dynamic activity and stretching	13	CMJ	GL	2 electrodes	Protocol (Kasman et al., 1998); ID: 2 cm	Shaving, rubbing

About the division of the jumps in phases, when a single phase is considered, most of the studies evaluated the take-off /push-off / propulsion / concentric / up-ward phase (n. of studies: 15), 3 studies respectively evaluated only the concentric phase or the landing/breaking phases. Other parameters considered were ground contact, the contraction phase, the time before the initiation of the jump, and the time between the start of the movement and take-off (1 study respectively). Different studies evaluated more phases. For the studies that evaluated 2 phases, the concentric / beginning / ascending / downward / braking phase and eccentric/ take-off / push-off / descending phase were the most studied (n. of studies: 12). Three phases were studied in 2 studies: braking, push-off, and take-off phase, and pre-activity, eccentric, concentric phase. One study evaluated four phases: eccentric, concentric, pre-activation, and landing phases. One study evaluated five phases: weighing, unweighting, braking, propulsion, flight, and landing. Five studies evaluated all the jumps not specifying the phases.

More detailed information is provided by some authors. For the force platform, the propulsion phase of each jumping style was identified as the duration from the changes in ground reaction force from the baseline to the time when both feet were lifted off the force plate (Charoenpanich et al., 2013). In another study the pre-activation was defined as 100 ms before the vertical force unloading phase, the end of the eccentric phase was defined as the time point at which vertical bar velocity became positive; the end of the concentric phase was defined as the point at which the force reached 0 (McBride et al., 2008). A study that adopted a motion capture system identified the pre-activation onset was set when the processed EMG signal exceeded 2 standard deviations of the EMG amplitude during standing and ended at touch-down; the braking phase was determined from the instant of movement initiation (CMJ) to the instant of the maximum knee flexion; the propulsion phase started from the maximum knee flexion until the take-off (Lazaridis et al., 2013).

The studies that did not adopt an instrument with the jump evaluation presented alternative and different strategies to evaluate the jump performance. One study recorded EMG signal from 400 ms before the

foot switch with the ground to 400 ms after the contact with the ground during the landing stage (ANBARIAN and AVAZZADEH SAMANI, 2022) not specifying how they detected this time. Furthermore, the authors (ANBARIAN and AVAZZADEH SAMANI, 2022) defined the concentric phase from the beginning to the peak; the flight phase from the peak to the eccentric phase, and the eccentric phase from the time of the collision of the feet to the off mode of leg muscle. One study (ANBARIAN and AVAZZADEH SAMANI, 2022), in the methodology explanation, adopted guidelines used in other articles (Pereira et al., 2008, Padulo et al., 2013). Earp and colleagues (Earp et al., 2016) recorded data for the start of the activity of the linear envelope reached 5 % of its maximum during movement, and did not drop below this value for 50 ms; for the end, the authors recorded data when the activity dropped below 5 % after movement was completed or in the case of a sustained submaximal contraction when activity decay ended. Two studies adopted similar strategies exploiting the standard deviation. The authors recorded the time between the start and when each signal reached a threshold of 2 standard deviations greater than that of a separate static standing trial (Harry et al., 2015, McKinlay et al., 2017) both adopting different protocols, previously published (Wulf et al., 2010, Hodges and Bui, 1996). Similarly, a study (MacKenzie et al., 2014) recorded the signal when it was greater than 20 % attained during trials, following protocols previously published (Baum and Li, 2003) and recognized (Kamen and Gabriel, 2010).

#### 3.4. The Standard Operating Procedure (SOP)

Based on the most adopted technique and common information extracted from the articles included, a SOP is proposed. Due to the characteristics of the studies, two SOPs are proposed. One was created for those studies that adopted other complementary instruments beyond surface EMG, and one for those studies that evaluated the CMJ and the SJ only with the surface EMG. Both SOPs will be deeply discussed in the next section of the manuscript.

**Table 2**  
Summary of the protocols followed in the included studies.

1 <sup>st</sup> author, year	Instrument / data	MVC / MVCI	Normalization	Jump analysis
Affi 2012 (Affi and Hinrichs, 2012)	Wireless; SF: 1200 Hz; BW: 20–4000 Hz	No	AVR EMG normalized to activation max during the takeoff phase of the CMJ	GRF. EMG AVR (100 ms) before Pk GRF and after impact
Akl 2013 (Akl, 2013)	16-ch, wireless. SF: 1000 Hz	No	RMS. EMG full-wave rectification by AVR RMS	GRF – MCS. Concentric and eccentric phase
Anbarian 2022 (Anbarian and Avazzadeh Samani, 2022)	16-ch, wireless. SF: 2000 Hz; BP: 10–500 Hz	MVIC	MF. Use of the highest MF in the MVIC test	From 400 ms before the foot switch with the ground to 400 ms after the contact with the ground during the landing stage
Arabatzis 2010 (Arabatzis et al., 2010)	16-ch, wireless. SF: 1000 Hz; BW: 8500 Hz	No	No Info	GRF. Full-wave rectified and AVR (0.60 intervals) over eccentric and Concentric Phase (CMJ) or during the whole SJ
Bond 2017 (Bond et al., 2017)	Wireless; SF: 1000 Hz; BP 20–500 Hz	MVIC	Normalized to the Pk activation during the MVIC and expressed as %	No Info
Charoenpanich 2013 (Charoenpanich et al., 2013):	Wireless; SF: 1500 Hz; filter: 25 Hz	MVC	100 Hz filtered and rectified EMG. % of MVC	GRF. Propulsion phase (duration from the changes in GRF from baseline to both feet were lifted off the force plate)
Clark 2020 (Clark et al., 2020)	2-ch, wireless; SF: 2000 Hz	DSN	RMS. AVR. Normalized to mean concentric phase RMS at 65 % system mass max	Goniometer and linear transducer data. Eccentric and concentric phase using the synchronized, and goniometer signal.
Cormie 2006 (Cormie et al., 2006)	8-ch, wireless; SF: 1000 Hz; BP: 10–200 Hz	No	Full-wave rectified	GRF. Eccentric plus concentric.
Donahue 2019 (Donahue et al., 2019)	8-ch, wireless; SF: 1000 Hz; BP: 20–250 Hz	MVC	AVR amplitude normalized as a % of Pk MVC (1 s)	GRF. AVR of the propulsion phase. The mean of 3 trials was used in the analysis. Means values of the % of MVC of the CMJ and SJ
Earp 2016 (Earp et al., 2016)	8-ch, wireless; SF: 2000 Hz; BP: 10–500 Hz	MVIC	RMS. % of MVIS. Max and AVR values.	Start: activity of the linear envelope reached 5 % of its max during movement, did not drop below this value for 50 ms. End: activity dropped below 5 % after movement was completed or in the case of a sustained submaximal contraction when activity decay ended.
Falch 2020 (Falch et al., 2020)	Wireless; SF: 1000 Hz; BP: 20–500 Hz	No	RMS.	MCS. Pk activation. The highest observed signals before take-off in the CMJ were used
Fletcher 2010 (Fletcher, 2010)	Wireless; SF: 1000 Hz	MVC	Rectified, integrated, and AVR over time. % of MVC	MCS. CMJ: from the start of the descent phase until take off. The SJ: from the start of the upward movement until take-off
Fukutani 2014 (Fukutani et al., 2014)	Wireless; SF: 4000; BP: 10–500 Hz	No	RMS. The Pk torque obtained during twitch contraction was adopted as twitch torque	MCS. AVR over 3 trials. The duration of measurement was set from when the knee joint was flexed maximally to when the toe lifted off the ground
Gheller 2014 (Gheller et al., 2014)	4-ch wireless; SF: 2000 Hz; BP: 20–500 Hz	No	RMS. Normalized to the highest RMS value obtained in the ascending phase	MCS. Ascending phase and descending phase
Giroux 2015 (Giroux et al., 2015)	Wireless; SF: 2000 Hz; BW: 10–400 Hz	MVIC	RMS. 100 ms rectangular window. Normalized to the RMSmax.	GRF. EMG timing was normalized as % of the complete duration of impulse every 0.1 % of the jump push-off phase. AVR RMS amplitude was quantified every 10 % throughout the push-off phase
Harry 2015 (Harry et al., 2015)	8-ch; SF: 2000 Hz; BP: 10–450 Hz	No	RMS. 10-second static standing trial. Pk and AVR.	The time between the start and when each signal reached a threshold 2 SDs greater than that of a separate 10-s static standing trial
Henderson 2019 (Henderson et al., 2019)	16-ch, wireless; SF: 1000 Hz; BP: 10–500 Hz	MVIC	% of MVIC	GRF. Take-off: the time the center of mass reached Pk downward acceleration, to the point at which system weight equaled 0 N
Hollville 2020 (Hollville et al., 2020)	Wireless; SF: 2000 Hz; BP: 10–450 Hz	No	RMS. Normalized to the AVR RMS values	MCS. AVR during the last 100 ms of the CM (downward phase), and during the push-off phase
Howard 2015 (Howard et al., 2015)	Wireless; SF: 2000 Hz; BW: 10–500 Hz	No	Mean AVR voltage. Normalized relative to the integration time	GRF. AVR over 2 CMJ calculated for the braking phase, push-off phase, and onset-of-force to takeoff
Jakobsen 2012 (Jakobsen et al., 2012)	Wireless; SF: 1000 Hz; BW: 10–10000 Hz	No	RMS. Pk rate of EMG rise was calculated as max slope of the rectified smoothed EMG-time curve normalized to Pk EMG amplitude	GRF. AVR EMG amplitude during the concentric phase of the CMJ
Jankaew 2024 (Jankaew et al., 2024)	Wireless; SF: 1000 Hz; BP: 20–450 Hz	MVIC	EMG median frequencies	GRF. 200 ms before ground contact, 200 ms after ground contact, and landing phase
Kannas 2015 (Kannas et al., 2015)	Wireless; SF: 1000 Hz; BW: 1.5–2000 Hz	No	Normalized with the EMG max during the propulsion phase	GRF. Maximum value over the three phases
Kopper 2012 (Kopper et al., 2013)	Wireless; SF: 1000 Hz; high-pass: 20 Hz	No	Full-wave rectification and smoothing	GRF-MCS. To determine muscle activation levels RMS EMG was calculated at 100 ms windows
Kovacs 2023 (Kovács et al., 2023)	Wireless; SF: 1000 Hz; BP: 20–450 Hz	No	RMS	MCS. Time (50 ms) RMS window was used
Kowal 2022 (Kowal et al., 2022)	2-ch; BP: 50–1000 Hz	MVC	RMS. Rectified and smoothed	Inertial sensor. Weighing, unweighing, braking, propulsion, flight, landing
Lamas 2012 (Lamas et al., 2012)	SF: 4800 Hz; BW: 20–500 Hz	MVIC	RMS. Normalized by the values obtained in the isometric leg press.	GRF-MCS. Signal during the contraction phase of both SJ and CMJ
Lazaridis 2013 (Lazaridis et al., 2013)	Wireless; SF: 1,000 Hz; BP: 10–500 Hz	No	Normalized to EMGmax value during each jump trial.	MCS. Braking (CMJ), and propulsion phase (SJ, CMJ). The pre-activation onset was set when the signal exceeded 2 SD of the EMG amplitude during standing and ended at touch-down

(continued on next page)

Table 2 (continued)

1 <sup>st</sup> author, year	Instrument / data	MVC / MVCI	Normalization	Jump analysis
Leporace 2011 (Leporace et al., 2011)	SF: 2,000 Hz; BP: 20-500 Hz	MVIC	RMS. Normalized to MVIC (1 sec)	Inertial sensor. To determine the initial ground contact, an electrical circuit was structured and connected to the inertial sensor
Lesinski 2016 (Lesinski et al., 2016)	Wireless; SF: 1500 Hz; BW: 10–750 Hz	No	Normalized to the pre-activation phase of the non-fatigued stable condition.	GRF. AVR during the braking phase, and the push-off phase. Values were averaged over three CMJ trials
Lowell 2024 (Lowell et al., 2024)	Wireless; SF:1000 Hz	MVIC	RMS. Normalized to MVIC	GRF. Each phase of the CMJ
Mackala 2013 (Mackala et al., 2013)	16-ch, wireless; BP: 10–300 Hz	MVC	RMS	The results are presented with the duration of the task scaled to equal 100 %.
Mackenzie 2014 (MacKenzie et al., 2014)	SF: 1000 Hz	No	Max raw signal, % of upward movement	Signal greater than 20 % attained during trials. Max and number of times each muscle was activated during the upward phase
Maixnerov 2019 (Maixnerová et al., 2019)	8 ch; SF: 1000 Hz	No	Resting EMG	GRF. Onset of EMG activity was calculated as baseline values + 10 % of the peak
Marchetti 2014 (Marchetti et al., 2014)	Wireless; SF: 1080 Hz; BP: 20–400 Hz	No	RMS. Normalized by the activation peak during the propulsive phase of the jumps.	GRF. Beginning and end of the CMJ propulsive phase
Marquez 2017 (Márquez et al., 2017)	8-ch, wireless; SF: 1500 Hz; BW: 10–500 Hz	MVIC	RMS. Normalized to % of the MVC	GRF. Eccentric, concentric phase, pre-activation (100 ms before initial contact), and landing phases (from the initial contact to the maximum displacement of the CoM after jumping)
Marquez 2009 (Marquez et al., 2009)	Wireless; SF: 1000 Hz; BW: 20–450 Hz	No	RMS. EMG recorded for the CMJ before was used as a baseline for normalization	GRF. Eccentric and concentric phase; time to reach the max value of RMS from the beginning of the jump
Masci 2010 (Masci et al., 2010)	Wireless; SF: 2000 Hz; BP: 10–500 Hz	No	ARV. Percentage of ARV max value	GRF. Time interval between the beginning of the jump and the take-off time instant
McBride 2008 (McBride et al., 2008)	8-ch, wireless; SF: 1000 Hz; BW: 10–500 Hz	No	Full wave-rectified	GRF. AVR integrated of pre-activity, eccentric, concentric phase
McHugh 2024 (McHugh et al., 2024)	16-ch, wireless; SF: 1000 Hz	MVIC	Pk and AVR % of MVV	GRF. Standing baseline (before initiation of the jump)
McKinlay 2017 (McKinlay et al., 2017)	SF: 1000 Hz; BP: 20–450 Hz	No	Mean amplitude. Baseline-activity	The point at which the EMG rose 2 SD above the of baseline-activity (first 500 ms) and remained elevated for at least 100 ms.
Mina 2018 (Mina et al., 2019)	Wireless; SF: 2000 Hz; BP: 20-500 Hz	MVIC	RMS. Normalized amplitude % of MVC	MCS. Peak and mean EMG activity were recorded during the eccentric and concentric phases.
Montalvo 2021 (Montalvo et al., 2021)	8-ch, wireless; SF: 1500 Hz; BP: 10–500 Hz	MVIC	RMS. 150 ms and normalized to % of MVC	No Info
Padulo 2013 (Padulo et al., 2013)	Wireless; SF: 1500 Hz;	MVIC	RMS. % of MVC	MCS. Values were calculated as the quotient of the EMG from dynamic trials divided by the EMG recorded from the MVC trials
Paschaleri 2024 (Paschaleri et al., 2024)	16-ch, wireless; SF: 1000 Hz; BW: 8500 Hz	No	RMS. Normalized to the max values derived from the same test	GRF. Eccentric and concentric phases
Peng 2023 (Peng et al., 2024)	Wireless; SF: 2000 Hz; BP: 20–500 Hz	No	RMS. EMG amplitude was normalized.	GRF. Take off. After extracting the EMG signals
Pinfold 2018 (Pinfold et al., 2018)	Wireless; SF: 3000 Hz; low pass 500 Hz	MVIC	RMS. Normalized to % of MVIC	MCS. From the time of first movement until ground contact of the CMJ
Rubio-Arias 2017 (Rubio-Arias et al., 2017)	8-ch; SF: 1000 Hz; BP: 8–500 Hz	No	RMS. EMGmax obtained in the take-off phase (EMG RMS % and EMG %)	GRF – ultrasound probes. Take-off phase
Russell 2007 (Russell et al., 2007)	Wireless; SF: 1080 Hz; BP: 20–500 Hz	No	RMS. Normalized to the within-trial peak rectified SEMG value	GRF. Landing phases
Salles 2011 (Salles et al., 2011)	16-ch; SF: 1000 Hz	No	EMG amplitude time integrals normalized to the 90–100 % condition for all jumps	GRF. Data were collected for a period of 10 s the data were first rectified and then integrated over time. The push-off phase
Shi 2023 (Shi et al., 2023)	Wireless; SF: 2000 Hz; BP: 10–400 Hz	No	RMS. Pk RMS during the 1 <sup>st</sup> repetition of the back squat was used for normalization	GRF-MCS. Eccentric and concentric phases
Sotiropoulos 2010 (Sotiropoulos et al., 2010)	SF:100 Hz; BP: 6–1500 Hz	MVIC	RMS. Normalized to the EMG recorded during a MVIC	Linear encoder and force sensor. Concentric phase
Wade 2020 (Wade et al., 2020)	Wireless; SF: 2000 Hz; BP: 30–350 Hz	No	RMS. Normalized to mean values recorded in the preferred CM	GRF-MCS. Take off
Walker 2010 (Walker et al., 2010)	Wireless; BP: 20–350 Hz	No	Max EMG was determined from the period 1500–2500 ms	GRF. The concentric phase for SJ is determined from the force deflection. EMG signals AVR for the concentric contraction
Wallmann 2008 (Wallmann et al., 2008)	Wireless; SF: 1000; BP: 45–350 Hz	No	No Info	GRF. AVR EMG is calculated during the jump phase by 1 <sup>st</sup> extracting data between the start of the movement and take-off

The SOP for those studies that want to analyze the jump without other complementary instruments was created based on the studies that presented only surface EMG protocols (for more details, see Table 2). As emerged from paragraph 3.3, for the EMG hardware, to have at least an 8-channel EMG is suggested. A sampling frequency with a bandwidth of 50–500 Hz should be adopted. The EMG recording should include the time between the start and when the signal reaches a threshold of 2

standard deviations or 20 % greater than that of a separate static standing trial. Another technique is the study of the period when the signal exceeds 2 standard deviations until landing or for a period of time of 100 ms to evaluate the performance during the jump. A representation of the SOP is presented in Table 3.

If the investigator has instruments, it is suggested to adopt a force platform, the ground reaction forces are a useful tool to identify the

**Table 3**  
Standard operating procedure summary for studies without complementary instruments.

Parameter	Description
<i>Hardware</i>	–Surface EMG (at least 8-channel EMG) –Sampling frequency of 1,000 Hz –Bandwidth to adopt should be 10 to 500 Hz
<i>Muscles</i>	Vastus lateralis, biceps femoris, gastrocnemius medialis, rectus femoris, vastus medialis, tibialis anterior, and gastrocnemius lateralis
<i>Electrodes</i>	Round silver-silver chloride electrodes (Ag-AgCl), 10 mm diameter
<i>Data extrapolation</i>	Normalization on a task with a similar drive
<i>Jump analysis (EMG signal to include)</i>	–Period between the start and when the signal reaches a threshold 2 standard deviations or 20 % greater than that of a static standing trial if the pre-activation wants to be studied –Period when the signal exceeds 2 standard deviations until landing –Period of 100 ms

jump phases and it is also the most adopted in the studies investigated. If a single phase is studied the take-off/propulsion is the most adopted in the literature. If two phases are of interest, the landing can be added. As done by different of the included studies summarized in Table 2), a goniometer could be helpful for an accurate monitoring of the angle at the knee. From the results extrapolated by paragraph 3.3, to collect data, a sampling frequency of 1,000 Hz is suggested. The bandwidth to adopt should be 10–500 Hz or 20–500 Hz. More than the previous SOP, the surface EMG should be wireless to facilitate the data collection process. More detailed for this SOP information is presented in Table 4.

Some aspects are similar in the two SOPs. The muscles that could be investigated, adopted in most of the studies included as presented in paragraph 3.1, are the vastus lateralis, biceps femoris, gastrocnemius medialis, rectus femoris, vastus medialis, tibialis anterior, and gastrocnemius lateralis. If a combination of 2 muscles is adopted, the binomial vastus lateralis-biceps femoris could be adopted. If 3 muscles want to be studied, vastus lateralis, vastus medialis, and biceps femoris are suggested.

The protocol could start with a maximal voluntary (isometric) contraction. In this way, it will be possible to normalize the data as a percentage of the maximal voluntary (isometric) contraction. If it is not possible to perform the maximal voluntary (isometric) contraction, some of the included articles, as presented in paragraph 3.3, normalized the data to the maximal muscle EMG activation during the take-off/propulsion of the jump or to the EMG recorded before the test or at rest. Data should be root mean squared.

According to the electrodes adopted in most of the articles, as presented in paragraph 3.2, should own the following characteristics: silver-silver chloride electrodes (Ag-AgCl); 10 mm diameter, and round. The rationale of this proposal is better explained in the discussion

**Table 4**  
Standard operating procedure summary for studies with complementary instruments.

Parameter	Description
<i>Hardware</i>	–Surface EMG, better if wireless –Sampling frequency of 1,000 Hz –Bandwidth to adopt should be 10–20 to 500 Hz
<i>Muscles</i>	Vastus lateralis, biceps femoris, gastrocnemius medialis, rectus femoris, vastus medialis, tibialis anterior, and gastrocnemius lateralis
<i>Electrodes</i>	Round silver-silver chloride electrodes (Ag-AgCl), 10 mm diameter –On the dominant leg
<i>Data extrapolation</i>	Normalization on a task with a similar drive
<i>Jump analysis (EMG signal to include)</i>	–Force Place –Motion capture –Goniometer

section. The interelectrode distance should be 2 cm. The electrodes should be placed on the dominant leg. To improve the quality of the evaluation, because most of the included studies (see Table 2) adopted the combination of shaving, abrading, and rubbing, it is suggested. SENIAM guidelines should be followed (Hermens et al., 2000).

#### 4. Discussion

The literature on the topic presents different protocols and procedures. Differences were detected in the electrode type and placement, in the muscles analyzed, in the protocol adopted, in the objectives, in the jump phases identification, and in the instruments adopted (for more details see Tables 1 and 2). Consequently, two SOPs are proposed to provide tools for future studies on this topic. Indeed, these SOPs could help the community in the data comparison and interpretation enabling high-quality meta-analysis, allowing the creation of a data bank, and increasing clinical reproducibility. The SOPs for the evaluation of the vertical jumps with and without complementary instruments are presented, in detail, in paragraph 3.4, and in Tables 3 and 4. A detailed explanation of the decision to propose these SOPs is in the next paragraphs of the discussion.

Different muscles were proposed in our SOPs with the vastus lateralis which was the muscle that most of the studies included investigated. On the other side, the biceps femoris was the second studied muscle. In general, the thigh muscles were the most studied and they were included in the SOPs (see Tables 2, 3, and 4). Muscles of the leg investigated at different times were the gastrocnemius medialis and tibialis anterior. Muscles of the thigh were the most studied because they are fundamental in the jump performance (Viitasalo and Bosco, 1982, Kipp and Kim, 2022). In muscle selection, it is known that an important role in the push-off phase is given by the hip extensor muscles (Lees et al., 2004, Bobbert et al., 1996) and consequently, they should be investigated to better understand the neuromuscular role behind the jump performance. Considering the role of the trunk and the upper limbs in the performance of the jump (Petrigna et al., 2019), it is also interesting to consider it to better understand the whole body's intermuscular coordination (BOBBERT and VAN INGEN SCHENAU, 1988). In this regard, the rectus abdominal, external oblique and erector spinae were the muscles studied more than a time of the trunk region. About the number of muscles to study, 2 or 3 muscles could be enough. The combination of vastus lateralis-biceps femoris (agonistic and antagonistic) was the most studied. To better evaluate and understand muscle performance, knowledge about muscle coactivation can help in understanding the neural control strategy (LATASH, 2018, Arai et al., 2013). Muscle coactivation can also help to better understand the fatigue process (LATASH, 2018). Consequently, we would like to suggest in the study of the surface EMG during vertical jumps to consider an agonistic-antagonistic combination. The decision to choose some muscle instead of another depends on the study's aim. If the interest of the study is around the knee, in terms of injury prevention or study stabilization, the hamstring muscles and gastrocnemius on one side, and the vastus lateralis and medialis on the other side, merit attention (Fagenbaum and Darling, 2003). When the sample is sex-specific, the muscle activity seems to be slightly different. During jumping, women present higher rectus femoris muscle activity and lower biceps femoris muscle activation (Hughes and Daily, 2015). Also, the vastus lateralis seems to be more active in females during jumps (Seyedahmadi et al., 2022). No differences were detected in the gastrocnemius medialis during landing (Hughes and Daily, 2015). Consequently, also in this case, the muscle should be chosen according to the sex of the participant.

The electrodes chosen and their positioning are fundamental elements for a correct and precise evaluation. The reliability of the evaluation depends on the position of the electrodes, the skin resistance, the cross-talk between muscles, and the jump mechanics (Goodwin et al., 1999). The study by Rainoldi and colleagues, could help in this regard providing the optimal electrode location between the innervation zone

and the tendon for the lower limbs (Rainoldi et al., 2004). The dimension and form of the electrodes should be a round 10 mm diameter placed on the dominant leg. We suggested these guidelines because most of the studies adopted them, but it depends on the type of study and the muscle investigated. This is important to avoid cross-talk such as for the surface EMG evaluation of the thigh where the signal of rectus femoris could overlap with the signals of the vastus muscles (Finni and Cheng, 2009). Different electrode configurations cannot be compared in terms of shape, size, and contact area (Campanini et al., 2022), consequently, it is fundamental in the comparison of different studies to consider this element. A confounding factor could be also the placement of adhesive discs to keep the electrode in place (Campanini et al., 2022). It should be to avoid this practice. For the above reasons, in the electrode placements and practices, it is fundamental to follow SENIAM guidelines (Hermens et al., 2000).

The decision on the type of hardware depends on the type of study and the objective. The number of channels depends on the type of study and its objective. Interesting is the option to adopt a linear array of multiple electrodes or multi-channel electrode arrays that can help to obtain more detailed information (Zwarts et al., 2000). The hardware must be able to sample at 1,000 Hz. A bandwidth of 10 to 500 Hz or 20–500 Hz is suggested (for more information see Table 2).

Normalization of the EMG signal is a fundamental aspect of making data comparable between muscles, studies, and subjects (Soderberg and Knutson, 2000). Normalization consists of rescaling data in percentage form (Burden and Bartlett, 1999). In the analysis, the normalization with the maximal voluntary (isometric) contraction was one of the most adopted techniques. According to Burden and colleagues, it seems that maximal voluntary isometric contraction depends on the training status influencing the normalization (BURDEN, 2010). Otherwise, other methodologies for normalization were adopted (Russell et al., 2007, Wade et al., 2020, Clark et al., 2020). Data were normalized to the peak values obtained during the trial. The authors supported their decision citing other studies (BASMAJIAN, 1985, Hodges and Bui, 1996, Dankaerts et al., 2004). It seems that with this technique, the within and between-day reliability and sensitivity are increased reducing the inter-subject variability (Yang and Winter, 1984, Dankaerts et al., 2004, Balshaw and Hunter, 2012). According to the literature the different normalization methodologies need to be adapted to the situation and the muscle contraction characteristics (Ball and Scurr, 2013). Normalization should be individualized to the contest to reduce intraindividual variability representing muscle activation (Ball and Scurr, 2013). For a high-velocity muscle action such as CMJs a normalization on a task with a similar drive could be suggested (Ball and Scurr, 2013). In the literature, it is possible to find detailed papers that provide guidelines for the correct collection, management, normalization, and analysis of the data (Soderberg and Knutson, 2000, Merletti et al., 2009), but not protocols for jump tests or specific motor movements, or during dynamic situations. This paper would like to be the first of a long series in this direction.

Force platforms were widely adopted to divide the vertical jumps into phases. This system is widely adopted to identify the phases of the vertical jumps (Eagles et al., 2015). The motion capture system is a reliable alternative for the jump analysis (Aleksic et al., 2024), especially from a biomechanical point of view. The important advantage of associating a force platform to surface EMG is possible to compare eccentric and concentric limb strength data (Nishiumi et al., 2023) with the EMG signal. This association is important, especially in neuromuscular training and in the prevention of anterior cruciate ligament injuries (Kiefer et al., 2015). But there are also some methodologies to evaluate the surface EMG during a jump. In our SOP we proposed the EMG recorded between the start and when the signal reaches a threshold of 2 standard deviations or 20 % greater than that of a separate static standing trial to evaluate the pre-activation. If the investigator wants to study the performance during the jump, it should take the period when the signal exceeds 2 standard deviations until landing or for a period of

time of 100 ms to evaluate the performance during the jump. Another technique is to use a general time from 400 ms before the foot switch with the ground to 400 ms after the contact with the ground during the landing stage (ANBARIAN and AVAZZADEH SAMANI, 2022).

In the SOP, a warm-up is not suggested. Indeed, some studies highlight how an isometric conditioning or stretching exercise are associated with EMG adaptations and H reflex excitability (Iglesias-Soler et al., 2011, Babault et al., 2023).

The study presents some limitations. First of all, it has been impossible to propose a deeper and more structured analysis of the topic. Due to a lack of information, such as more details of the hardware adopted or related to the procedures followed, some of the results are still general. Furthermore, there are important gaps in the literature that require attention. Indeed, the studies included were performed on different populations with different objectives. Specific SOPs based on the population characteristics (age, clinical or sporting setting, sports characteristics) should be generated only if in the presence of studies that allow this type of extrapolation. The proposal of SOPs based on the objective (i.e., the study of the biomechanics of the jump or the study of the neuromuscular system), in the future could be thought. At this moment, due to the high heterogeneity of the objectives of the studies included, it is impossible to create objective-related SOPs. Otherwise, our SOP wants to be a first step in this direction. An important limitation was the lack of other jump techniques such as the drop jump. We intended to include the three vertical jumps most adopted but due to the nature of this jump technique, we preferred to focus the attention on the two jumps where there is a similar pattern. Future studies could focus attention on other jump techniques and motor activities. Limitations are also related to the EMG hardware. Some studies did not provide an indication of the manufacturing company making even harder the categorization of this part. Furthermore, considering the information that can be obtained with a linear electrode array that provides indications about motor unit properties, muscle fiber conduction velocity, and properties with a global and accurate vision of the neuromuscular system (Merletti et al., 2003), future studies should be focalized also in this aspect. One last limit could be related to the lack of specific guidelines for the normalization and the jump phase identification due to the lack of consistent data. Future studies could focus attention on these aspects. They could also evaluate if there are differences in terms of the level of activity of the participants. Also, the segmental percentage of body fat and muscle mass could be an interesting factor to be considered as a confounding factor and that could help in a better understating of the standardization of the evaluation. A final aspect to consider could be the role of the expertise of the participant in the jump execution, from a neuromuscular point of view this could influence the performance.

## 5. Conclusions

Different methodologies were adopted in the included studies both, in the protocol and the technique adopted. Consequently, SOPs are proposed and discussed based on the most adopted technique and common information extracted from the articles included. The manuscript wants to provide a tool to help the community better evaluate the CMJ and SJ from a neuromuscular point of view. It is the first time that the concept of SOP is associated with surface EMG and we would like to provide a starting point for future research in this contest. From a practical point of view, standardized guidelines allow an easier reading of the results. The SOPs could be adopted in different fields, such as in sports performance testing and monitoring, in clinical testing and rehabilitation, or in research field. Finally, our proposed SOPs are only an initial point of start. The SOPs should be updated according to technological advancement such as high-density or wearable EMG systems making them actual and attractive.

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## CRedit authorship contribution statement

**Luca Petrigna:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Alessandra Amato:** Writing – original draft, Formal analysis, Data curation, Conceptualization. **Giorgia Longo:** Writing – original draft, Investigation, Formal analysis, Data curation. **Alessandro Castorina:** Writing – review & editing, Conceptualization. **Simona Pajaujiene:** Writing – review & editing, Data curation, Conceptualization. **Giuseppe Musumeci:** Writing – review & editing, Supervision, Methodology, Data curation, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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