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campus savona

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Ankle landing biomechanics in chronic ankle instability and healthy subjects: implication for injury prevention and clinical implication.

Candidati:

Dott. Giacomo Boni

Dott. Matteo Bosco

Relatore:

Dott. Giacomo Maffioletti

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1. ABSTRACT

Background: Chronic Ankle Instability (CAI) is a largely common musculoskeletal problem affecting people with a significant past episode of Lateral Ankle Sprain (LAS) which causes serious consequences in everyday activity and sports. Since ankles, knees and hips are part of a single kinetic chain, a change in the kinematics of one of these joints consequently involves a change in the others. This is why changes in ankle function associated with CAI may predispose patients for non-contact injuries, especially in high impact task such as, for example, landing.

Objective: The aim of this review is summarizing the existing evidence in literature about ankle and lower extremity biomechanics during landing phase both in healthy subjects and CAI subjects. The arisen differences between the two groups will allow to develop and suggest strategies for injury prevention and treatment clinical implications.

Methods: The review was conducted by two reviewers. Examined databases are Pubmed, Cochrane, Embase, Pedro, Scopus, Web of science. Eligibility criteria are English language and full-text articles. Articles were selected according to titles and abstracts. Moreover, they had to meet the definition of CAI and analyze the landing biomechanics. In order to have comparable and homogeneous data the intervention taken into account is the "single leg drop jump" test. A BIAS risk evaluation was made for each study selected for the present paper using the STROBE checklist.

Results: 17 studies were included in this review. 7 assess the CAI group in comparison with a healthy subject, 1 compares CAI with Coper, 2 compare CAI with both Coper and Healthy subjects, 1 assesses CAI subjects only, 5 healthy subjects only, 1 follows a group of injured subjects up to one year from injury. As for the kinematics of the lower limb in the landing phase, it was not possible to agree on the results of the various studies, both between healthy subjects and CAI vs healthy and CAI vs Coper ones.

Conclusion: In the comparison between CAI and Healthy subjects, no evidence was found to make assumptions regarding the difference in kinematics of the ankle and more generally of the lower limb during landing from a jump. Future studies should use standardized procedures to reduce the heterogeneity found and make the data more comparable.

2. INTRODUCTION

Chronic ankle instability (CAI) is a clinic condition that affects up to 70% of patients with a history of lateral ankle sprain (LAS)[17]. It has been shown that CAI is characterized by pain[10], decrease ROM and strength[3], impaired proprioception[15,16,37], balance[10,13,20,25,33], neuromuscular control[5,15,21] and altered functional activities[10,13,15]. LAS is the most prevalent musculoskeletal injury in physically active people[17] and commonly occurs in sports with a high level of jumping and cutting activities[10] such as handball, basketball, soccer and volleyball. Being CAI a highly prevalent condition (>25%) in these sports[10,] this aim of this review is to analyze, summarize and compare the existing evidence in literature about ankle and lower extremity biomechanics during landing phase both in healthy subjects and CAI subjects. The arisen differences between the two groups will allow to develop and suggest strategies for injury prevention and treatment clinical implications.

3. MATERIALS AND METHODS

In order to carry out and draw up this systematic review, the proposals of the PRISMA statement[28] were followed. The adopted eligibility criteria refer to PICOS query (P - population, I – Intervention, C – Comparator, O – Outcomes, and S – Study design) that is as follows : "Are there any differences in jump landing biomechanics between a healthy subject and one with Chronic Ankle Instability? And if there are any, is it possible to make assumptions about prevention and treatment?". The analyzed population is represented by subjects affected by CAI, identified with the inclusion and exclusion criteria adopted by the Position Statement of the International Ankle Consortium[18], in order to have a study population as homogeneous as possible; these criteria are reported in Table 1 and Table 2.

Table 1. Standard Inclusion Criteria Endorsed, as a Minimum, by the International Ankle Consortium for Enrolling Patients that Fall Within the Heterogeneous Condition of Chronic Ankle Instability in Controlled Research

Inclusion Criteria
1. A history of at least 1 significant ankle sprain The initial sprain must have occurred at least 12 months prior to study enrollment Was associated with inflammatory symptoms (pain, swelling, etc) Created at least 1 interrupted day of desired physical activity The most recent injury must have occurred more than 3 months prior to study enrollment. We endorse the definition of an ankle sprain as ''An acute traumatic injury to the lateral ligament complex of the ankle joint as a result of excessive inversion of the rear foot or a combined plantar flexion and adduction of the foot. This usually results in some initial deficits of function and disability.''
2. A history of the previously injured ankle joint ''giving way'' and/or recurrent sprain and/or ''feelings of instability.'' We endorse the definition of ''giving way'' as ''The regular occurrence of uncontrolled and unpredictable episodes of excessive inversion of the rear foot (usually experienced during initial contact during walking or running), which do not result in an acute lateral ankle sprain.'' Specifically, participants should report at least 2 episodes of giving way in the 6 months prior to study enrollment. We endorse the definition of ''recurrent sprain'' as two or more sprains to the same ankle. We endorse the definition of ''feeling of ankle joint instability'' as ''The situation whereby during activities of daily living (ADL) and sporting activities the participant feels that the ankle joint is unstable and is usually associated with the fear of sustaining an acute ligament sprain.'' Specifically, self-reported ankle instability should be confirmed with a validated ankle instability specific questionnaire using the associated cut-off score. Currently recommended questionnaires: a. Ankle Instability Instrument (AII): answer ''yes'' to at least 5 yes/no questions (This should include question 1, plus 4 others.) b. Cumberland Ankle Instability Tool (CAIT): <24 c. Identification of Functional Ankle Instability (IdFAI): > 11
3. A general self-reported foot and ankle function questionnaire is recommended to describe the level of disability of the cohort, but should onlybe an inclusion criterion if the level of self-reported function is important to the research question. Currently endorsed questionnaires: a. Foot and Ankle Ability Measure (FAAM): ADL scale < 90%, Sport scale < 80% b. Foot and Ankle Outcome Score (FAOS): < 75% in 3 or more categories

Table 2. Standard Exclusion Criteria Endorsed, as a Minimum, by the International Ankle Consortium for Enrolling Patients that Fall Within the Heterogeneous Condition of Chronic Ankle Instability in Controlled Research

Exclusion Criteria
1. A history of previous surgeries to the musculoskeletal structures (ie,bones, joint structures, nerves) in either limb of the lower extremity It is understood and accepted in clinical and research practice that surgery to repair insufficient joint structures is designed to restore structural integrity but creates residual changes in the central and peripheral portions of the nervous system. Even with appropriate rehabilitation and follow-up management, there are concomitant neuromuscular and structural alterations after surgery that would confound the ability to isolate the effects of chronic ankle instability.
2. A history of a fracture in either limb of the lower extremity requiringrealignment Similar to the first exclusion criterion, significant compromise to skeletal tissue will threaten the internal validity of the selection of study populations with isolated chronic ankle instability.
3. Acute injury to musculoskeletal structures of other joints of thelower extremity in the previous 3 months, which impacted joint integrity and function (ie, sprains, fractures) resulting in at least 1 interrupted day of desired physical activity

Control is represented by healthy subjects, who have never suffered from injuries to the ankles or, more generally, to the lower limbs; Coper subjects are also included as controls in some studies, as Coper are individuals who, after an initial episode of Lateral Ankle Sprain, returned to previous activities without any limitations. Since the aim of this study is to evaluate the jump landing, there was the need to standardize the task considered for data analysis, in order to have comparable and homogeneous data. Therefore the intervention taken into account is the "single leg drop jump" test: the subject, placed on a box of variable height and standing in a monopodalic upright position, takes a jump to the ground, landing on the limb under investigation (injured for the CAI or Coper, the dominant limb or matched for healthy) and reaches a balance condition, as quickly as possible. The assessed outcomes are the biomechanical and kinematic analysis of the ankle and, eventually, that of the other lower limb's joint during the initial contact with the ground, but also the moments immediately before and after the initial contact. Finally, as for the study types to be included in this review, no limits were set, except for the exclusion of other systematic reviews. Articles in which the population is not affected by CAI were excluded from the study, referring to criteria listed above, but not considering them binding in their entirety (accepting therefore, although with reserve, subject with Mechanical and Functional Instability). Articles in which the task was different from the single leg drop jump (e.g. drop vertical jump, single leg jump, single hop jump, etc.) or carried out in a condition other than regular (after fatigue protocols or rehabilitation, with orthosis, landing on unstable ground, in contexts different from laboratory) or with different outcomes (such as Ground reaction force or EMG analysis) were also excluded. This review was conducted by two reviewers (BG and BM) while a third person (MG) supervised it. Firstly, an exploratory research was conducted on Pubmed (keywords: chronic ankle instability, healthy subjects, landing, biomechanical), in order to identify the keywords needed for the strings. Then, Pubmed, Pedro, Cochrane Library, Web of Science and Scopus databases have been consulted: for each of these databases, a search string has been set both for CAI and healthy subjects. Research strategies and their execution dates are shown in Table 3. No time or language limits have been set. Furthermore, the bibliographic references of the included studies and other relevant systematic reviews have been consulted.

	Healthy	CAI
PUBMED	(((((((((((((Healthy Volunteers[MeSH Terms]) OR Healthy Volunteer[Title/Abstract]) OR Healthy Volunteers[Title/Abstract]) OR Healthy Participant[Title/Abstract]) OR Healthy Participants[Title/Abstract]) OR Healthy Subject[Title/Abstract]) OR Healthy Subjects[Title/Abstract]) OR healthy[Title/Abstract]) OR subjects[Title/Abstract])) AND ankle[Title/Abstract])) AND (((((((((((biomechanical phenomena[MeSH Terms]) OR biomechanical phenomena[Title/Abstract]) OR biomechanical phenomenas[Title/Abstract]) OR biomechanic phenomenas[Title/Abstract]) OR mechanobiological phenomena[Title/Abstract]) OR biomechanical[Title/Abstract]) OR biomechanic[Title/Abstract]) OR biomechanics[Title/Abstract]) OR kinetic[Title/Abstract]) OR kinetics[Title/Abstract]) OR kinematic[Title/Abstract]) OR kinematics[Title/Abstract])) AND ((((((landing[Title/Abstract]) OR landing phase[Title/Abstract]) OR impact[Title/Abstract]) OR impact phase[Title/Abstract])) OR ground reaction force[Title/Abstract])) AND ((ankle joint[MeSH Terms]) OR ankle[Title/Abstract])) 12/10/2019	((((((((biomechanical phenomena[MeSH Terms]) OR biomechanical phenomen*) OR biomechanic phenomen*) OR mechanobiological phenomen*) OR biomechani*) OR kineti*) OR kinemati*)) AND (((((impact phase) OR impact) OR ground reaction force) OR landing) OR landing phase)) AND ((((((((((chronic ankle instability) OR chronic ankle lateral instability) OR mechanical ankle instability) OR functional ankle instability) OR lateral ankle instability) OR ankle instability) OR ankle sprains) OR recurrent ankle instability) OR recurrent ankle sprain) OR recurrent ankle injury) 7/3/2020
PEDRO	kinematic ankle landing 12/10/2019	ankle instabil* biomec* 7/3/2020

SCOPUS	(TITLE-ABS-KEY (biomec* OR kinematic) AND TITLE-ABS-KEY (ankle) AND TITLE-ABS-KEY (healthy) AND TITLE-ABS-KEY (landing)) 12/10/2019	((((((((biomechanical AND phenomena) OR biomechanical AND phenomen*) OR biomechanic AND phenomen*) OR mechanobiological AND phenomen*) OR biomechani*) OR kineti*) OR kinemati*)) AND (((((impact AND phase) OR impact) OR ground AND reaction AND force) OR landing) OR landing AND phase)) AND (((((((((chronic AND ankle AND instability) OR chronic AND ankle AND lateral AND instability) OR mechanical AND ankle AND instability) OR functional AND ankle AND instability) OR lateral AND ankle AND instability) OR ankle AND instability) OR ankle AND sprains) OR recurrent AND ankle AND instability) OR recurrent AND ankle AND sprain) OR recurrent AND ankle AND injury)
WEB OF SCIENCE	(TS=(ankle AND landing AND healthy) AND TS=(Biomec* OR kinetic)) 12/10/2019	((((((((biomechanical phenomena) OR biomechanical phenomen*) OR biomechanic phenomen*) OR mechanobiological phenomen*) OR biomechani*) OR kineti*) OR kinemati*)) AND (((((impact phase) OR impact) OR ground reaction force) OR landing) OR landing phase)) AND (((((((((chronic ankle instability) OR chronic ankle lateral instability) OR mechanical ankle instability) OR functional ankle instability) OR lateral ankle instability) OR ankle instability) OR ankle sprains) OR recurrent ankle instability) OR recurrent ankle sprain) OR recurrent ankle injury)) 7/3/20

CHOCRANE LIBRARY	ID Search Hits #1 MeSH descriptor: [Biomechanical Phenomena] explode all trees 2739 #2 ("kinematics"):ti,ab,kw 1700 #3 MeSH descriptor: [Healthy Volunteers] explode all trees 2907 #4 (healthy subject):ti,ab,kw 9853 #5 MeSH descriptor: [Ankle] explode all trees 477 #6 (ankle):ti,ab,kw 8721 #7 (landing):ti,ab,kw 431 #8 #1 OR #2 3911 #9 #3 OR #4 12560 #10 #5 OR #6 8721 #11 #8 AND #9 AND #10 AND #7 4 12/10/2019	ID Search Hits #1 impact phase OR impact OR landing OR landing phase OR ground reaction force 107320 #2 (chronic ankle instability OR chronic ankle lateral instability OR mechanical ankle instability OR functional ankle instability OR lateral ankle instability OR ankle instability OR recurrent ankle instability OR recurrent ankle sprain OR recurrent ankle injury):ti,ab,kw (Word variations have been searched) 550 #3 #1 OR ankle sprains 107875 #4 #1 AND #2 42 #5 biomechanical phenomen* OR biomechanic phenomen* OR mechanobiological phenomen* OR biomechani* OR kineti* OR kinemati* 17477 #6 #1 AND #2 AND #5 21 #7 MeSH descriptor: [Biomechanical Phenomena] explode all trees 2739 #8 #7 OR #5 17543 #9 #1 AND #2 AND #8 21 #10 #2 AND (#1 OR #5) 42 7/3/2020

Table 3

Two reviewers extracted each research results: the first one analyzed CAI results while the other one studied the healthy subjects, selecting independently the useful articles to be included, but submitting any indecisions to the supervisor. The selection process consisted of different steps: a preliminary duplicate results elimination, a screening by title and abstract, and, lastly, the examination of remaining articles full text and their comparison to the eligibility criteria. These steps can be seen in the PRISMA 2009 flow diagram submitted in the results section (Table 4 and Table 5). After establishing which studies to include in this review (for both CAI and healthy subjects), data were extrapolated from reports and tabulated, in order to summarize all the evidences. This synoptic table, displayed in the results section (Table 6), includes PICOS items and it is structured as follows: Author and year, Population (sex, personal and anthropometric data and, if any, number of injury episodes and distance from the last event, scores of the various questionnaires), Control (same data of the Population column but of Healthy and Coper subject), Intervention and Outcomes (description of the task, the measured variable and measurement method), Results (ROM of the ankle and other joints in the different planes and in different landing phases and conclusions). In order to solve any doubts, table contents were discussed with the supervisor. As for each study risk of bias evaluation, it was decided to use STROBE checklist[36], since our target is observational studies and there is no a set gold standard for the analysis of these reports. This tool, originally designed as a guideline for observational studies reports, was used in order to evaluate the completeness and the potential bias in all the observational studies included in this review. For this purpose, both reviewers completed each study checklists, giving to each of the 22 items a score of: 0 in the event of items not reported or methodologically incorrect; 1 if present and so well exposed not to leave any doubts about the possibility of bias. These scores were finally added up and converted into a percentage, attributing a meaning of "critical risk of bias" to a score between 0-25%, "serious risk of bias" to 26-50%, "moderate risk of bias" to 51- 75%, "low risk of bias" to 76% - 100%. As for the shared articles between the two authors, an agreement was reached by comparison, then endorsed by the supervisor. The related table is displayed in the results section (Table 9). The meaning given to item scores and their global interpretation, in the absence of a gold standard of reference, was elaborated by the authors in agreement with the supervisor, though referring to other bias risk assessment tools such as ROBINS- I[7] and its scores.

4. RESULTS

As for the CAI search strategy, from the search in the selected databases, 1383 eligible articles were found: 541 articles from PubMed, 103 from Cochrane Library, 9 from PEDro, 275 from Web of Science and 455 from Scopus. The removal of duplicates allowed to eliminate 245, reaching a total of 1138 articles; 549 of these were eliminated after reading the title, 534 after reading the abstract, as not relevant to the PICO query, reducing the number of articles still eligible to 55. The full-text of these remaining articles was read and compared with the eligibility criteria: 15 studies were excluded as they also included other interventions besides the jump (e.g. application of tapes and braces, manual therapy interventions, exercise protocols or jump training) that could modify the execution, 27 were eliminated because the task examined was different from the single leg drop jump (e.g. single leg vertical jump, cutting, drop vertical jump) or were executed in contexts other than the laboratory (soccer fields, landing on soft or unstable surfaces) and finally 1 was eliminated as in the population it was not specified which subjects suffered from knee instability and which from ankle one. In conclusion, 12 articles were included in the study. All the steps are displayed in Table 4.

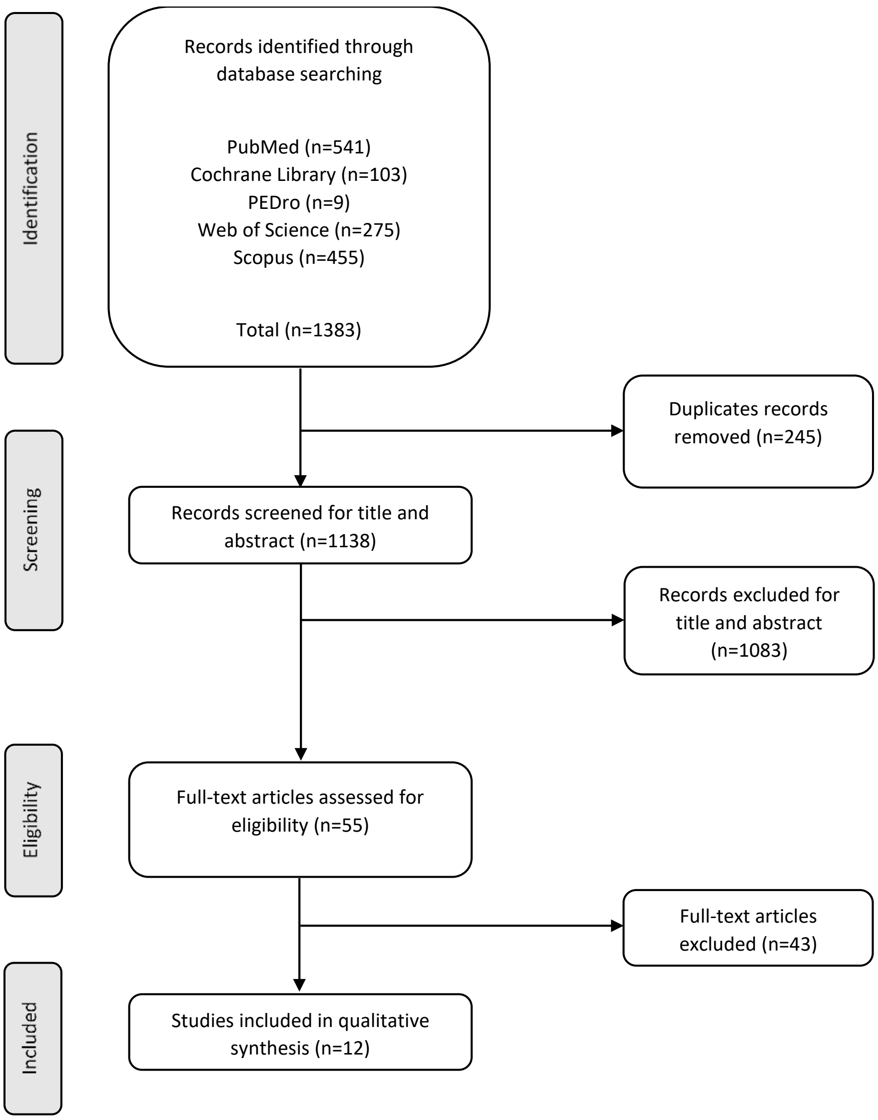

Table 4

Analyzing and launching the string about healthy people in the databases, 801 eligible articles were found, 554 of which were from PubMed, 4 from Cochrane Library, 1 from PEDro, 112 from Web of Science and 130 from Scopus. The removal of duplicates allowed to eliminate 191, reaching a total of 610 articles; of these 532 were eliminated after reading the title and the abstract, reducing the number of articles still eligible to 78. After reading the full text and comparing them with the eligibility criteria, 69 articles were excluded. In conclusion, 9 articles were included in the study. The selection process is displayed in Table 5.

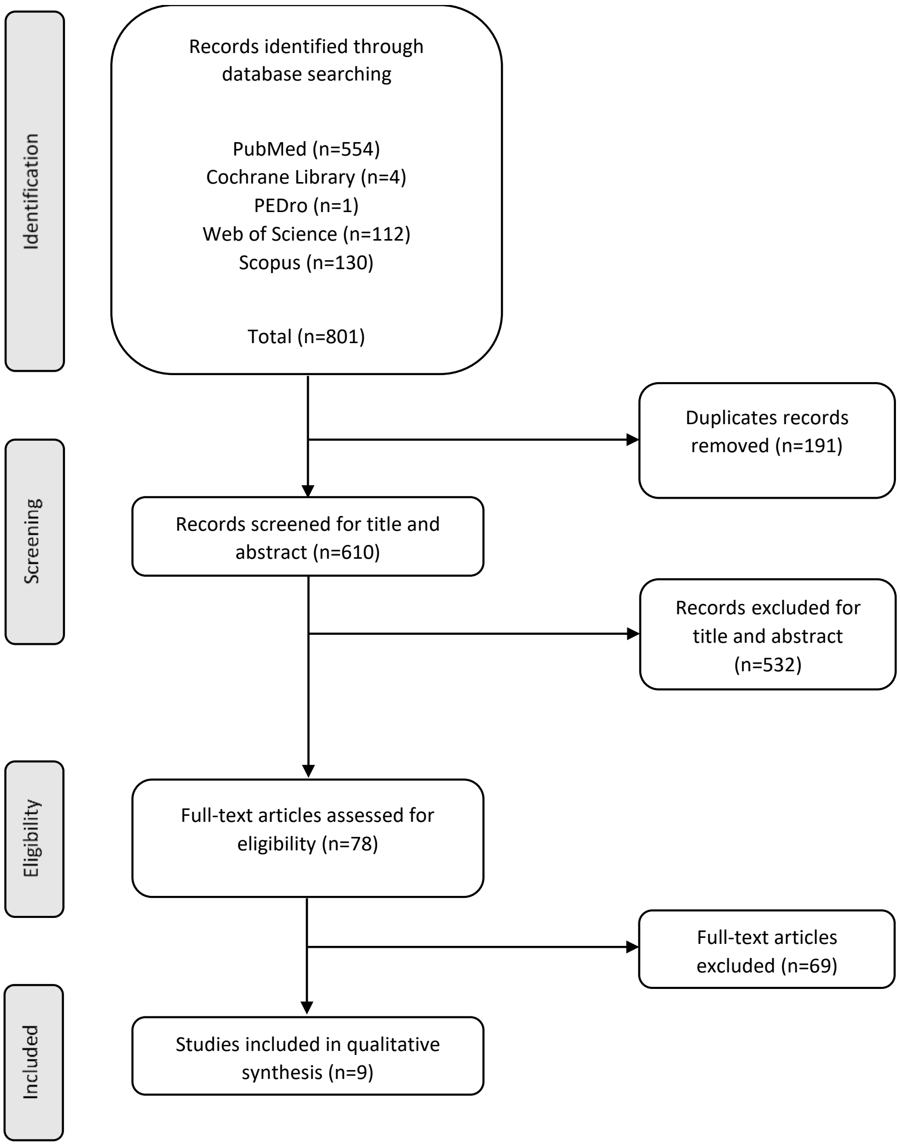

Table 5

Combining the results of the two searches, 21 articles resulted, 4 of which in common, for a definitive number of 17 articles to be included in the review. Next, a synoptic table was compiled, which summarizes the characteristics and results of each study considered eligible; this table is available below (Table 6).

Author and Year	Population	Control	Intervention and Outcome	Results
Ali et all. 2014 (A)		6 (3M,3F) Mean (SD) M Age, y 22.8 (1.60) Height, m 1.80 (0.03) Weight, kg 67.28 (3.52) F Age, y 21.6 (1.20) Height, 1.71 (0.02) Weight, kg 64.71 (2.33)	1 single leg jump from three different heights: 20, 40, and 60 cm into a force plate placed 30 cm away from the box. Ankle, knee and hip flexion angle were misured.	Ankle flexion angle (deg) M 20cm 48.09 ± 2.58 40cm 51.47 ± 2.47 60cm 51.97 ± 6.49 F 20cm 49.92 ± 5.92 40cm 50.19 ± 12.01 60cm 50.47 ± 8.37 Knee flexion angle (deg) M 20cm 54.67 ± 4.61 40cm 60.54 ± 0.88 60cm 71.23 ± 8.77 F 20cm 47.21 ± 7.35 40cm 52.66 ± 11.24 60cm 65.05 ± 2.65 Hip flexion angle (deg) M 20cm 19.27 ± 5.97 40cm 26.51 ± 2.90 60cm 31.07 ± 8.03 F 20cm 24.38 ± 4.14 40cm 23.70 ± 7.64 60cm 33.78 ± 11.65
Ali et all. 2014 (B)		9 M Mean (SD) Age, y 27.67 (2.56) Height, m 1.75 (0.077) Weight, kg 78.12 (8.59	1 single leg jump from three different heights: 20, 40, and 60 cm into a force plate placed 20 cm away from the box. Ankle, knee and hip flexion angle were misured. Ankle dorsiflexion is defined as positive, knee flexion as negative, hip flexion as positive.	Ankle plantar flexion angle (deg) Means ± SD: 20cm −0.22±3.52 40cm −2.11±2.44 60cm −2.67±3.54 Knee flexion angle (deg) Means ± SD: 20cm −30.88±5.89 40cm −32.92±3.00 60cm −35.89±2.30 Hip flexion angle (deg) Means ± SD: 20cm 23.31±7.34 40cm 19.02±5.53 60cm 21.04±6.94
Brown et all. 2008	21 Mechanical Ankle Instability (MAI): 11M e 10W, Age 22.38+/-4.30y, height 173.40+/-10.57cm, mass71.49+/13.03kg, Fadi 89.13+/-8.11 e Fadi-s 76.62+/-12.24. + Anterior Drawer and Talar Tilt test. 21 Functional Ankle Instability (FAI): M11 e	21 COPER: 11 Males e 10 W, a: 21.71+/-4.85y, h: 175.24+/-8.75cm, m: 69.92+/-10.66kg, Fadi 97.04+/4.13 e Fadi-s 90.98+/-9.73. - Ant Drawer and Talar Tilt test.	5 tasks (2 of interest for us): 8 stepping up and over a 32 cm high box (step down), 8 single leg drop jump from a box of height 32 cm. 8 Drop jump trials, subjects were instructed not to jump “up” off the box but instead to “step off”, subject	STEP DOWN: MAI demonstrated less ankle sagittal plane displacement than both the FAI and COPER (MAI44.92 vs FAI 53.10 vs C 53.43) and greater ankle frontal plane displacement than the COPER (MAI 15,02 vs C 9,36). No other ankle, knee variables were significantly differents.

	10W, A: 22.14+/-3.83y, h: 171.90+/- 9.58 cm, m: 2.98 +/- 13.14. Fadi 94.19+/-4.30 e Fadi-s 81.53+/-10.26. - Anterior Drawer and Talar Tilt test.		balanced for approximately 3 s at the end of each drop jump trial. The dependent variables identified in each trial were ankle and knee sagittal and frontal plane angles at initial contact, at maximum, and the total displacement during the stance phase.	DROP JUMP: The MAI landed with less plantar flexion at initial contact (MAI 28,36 vs C 35,03) and at maximum (MAI 28,37 vs C 35,03) than the COPER; MAI also landed with greater maximum eversion (MAI 6,22 vs FAI 2,20 vs C 2,17) and less sagittal plane displacement (MAI 41,55 vs FAI 49,32 vs C 51,80) than the FAI and COPER.
Caulfield et all. 2002	14 FI subjects, male, 26.6 +/- 6.3 years, 77.1 +/- 9.1kg.	10 CONTROL subjects, male, 22.6 +/- 4.6 years, 71.4 +/- 9.7kg.	5 Single leg drop jumps from a height of 40 cm onto a force plate. Knee and ankle joint angular displacement in the saggital plane during the period from 100ms prior to landing to 200ms post landing, were identified for each jump performed by subjects.	Analysis of differences in joint displacment: ANKLE: there was statistical significal difference at all intervals from 10 ms pre-impact (at 0 time FI 2.8 °+/-1.0 vs Control -4.4°+/-2.4) to 20 ms post impact (F 10.1+/-0.9 vs C 5.4+/-1.6). KNEE: there was statistical significal difference between 20 ms pre-impact (F18.0°+/-0.7 vs C 13.3°+/-1.6) at 0 (F 25.8°+/-1.0vs C 19.4°+/-1.4) at 20 (F34.6° +/-1.3 vs C 27.3°+/-1.5) at 40 (F41.7°+/-1.2 vs C 34.9°+/-1.6) and 60ms post-impact.
De Ridder et all. 2015	CAI group: 38 subjects (19M and 19 W, A:22.1 (3.4)*y, h:175.4 (8.3)cm, BMI:23.1 (3.4), Fadi 89.2 (7.2)* Fadi-s 72.7, 5* (SD 3) months to last sprain, 10 (SD 13) sprains annually).	COPERS group: 28 subjects (14M and 14F, A:20.3(1.9)*y, h:177.6 (10.2), BMI:22.1 (1.7), Fadi 99.0 (2.4)*, fadi-s 96.2 (4.8)*, 11 (SD 5) months to last sprain). CONTROL group: 30 subjects (12M and 18W, A:25.7 (1.8)*y, h:173.6 (9.4)cm, BMI:21.8 (1.8), Fadi e Fadi-s 100*).	2 landing task, 1 of interest for us, 3 SINGLE LEG DROP JUMP from a 40 cm high box: they were instructed not to jump but rather to step down and to maintain balance for 3 seconds. Joint kinematics were calculated for the impact phase until maximal dorsiflexion in the ankle joint (maxDF).	Subjects with ankle instability had a greater midfoot inversion/eversion range of motion than copers during the vertical drop. Copers exhibited less plantar flexion/dorsiflexion range of motion in the lateral and medial forefoot. Furthermore, the ankle instability and coper group exhibited less ankle plantar flexion at touchdown.

			Additionally, range of motion was determined for each joint in all planes during the impact phase.	Additionally, the ankle instability group demonstrated a decreased plantar flexion/dorsiflexion range of motion at the ankle compared to the control group.
Delahunt et all. 2006	24 FI subjects (15 M, 9W) A 25+/-1.3*, H 1.74+/-0.01, W 72.08+/-2.06, and BMI 23.76+/-0.49.	24 CONTROL subjects (16 male, 8 female) Age 22+/-0.84, Height 1.76+/-0.01, Body Mass 70.87+/-1,9, and Body Mass Index 22.72+/-0,41.	10 single leg drop jumps from a height of 35 cm onto a force plate. The period from 200-ms pre-IC to 200-ms post-IC was identified for each subject. Time-averaged profiles for hip, knee, and ankle joint 3D angular displacements and velocities were calculated for each subject.	FI subjects had a more inverted position of the ankle joint during the time period from 200-ms–95-ms pre-IC. FI subjects also had a less dorsiflex position of the ankle joint during the time period from 90-ms–200-ms post-IC. Subjects with FI also exhibited a change in sagittal plane ankle joint angular velocity, whereby during the time period 50-ms–125-ms post-IC they were moving towards a dorsiflex position of the ankle joint at a slower rate than control subjects. FI subjects also had a less externally rotated position of the hip joint during the time period from 200-ms–55-ms pre-IC.
Doherty et all. 2015	57 participants (34M and 21W, mean age of 22.6 y, mean height of 1.72 m, mean body mass of 74.7 kg CAIT21.44 ± 5.90° FAAMadl 95.78 ± 5.82 FAAMsport 83.72 ± 13.41)	CONTROL group of 20 participants (15M and 5W, mean age of 22.6 y, mean height of 1.73 m, mean body mass of 71.4 kg, CAIT 30 FAAMadl and sport 100)	3 Single leg drop jumps from 0,4 m onto a platform, upon landing, participants were required to balance as quickly as possible on the test leg and hold this position for approximately 4–6s. Time-averaged three-dimensional angular displacement profiles for the hip, knee, and ankle joints were calculated for each limb of all	Time-averaged three-dimensional kinematic profiles comparing matched limbs (LAS involved vs control involved; LAS uninvolved vs control uninvolved) revealed that the LAS group displayed altered movement patterns compared with control participants in sagittal plane hip motion (IL increased flexion from 88ms to 176ms post IC and NIL from 56ms to 144ms post IC 200ms) on both limbs, sagittal

			participants from 200 ms pre-IC to 200 ms post-IC.	plane knee motion on the uninvolved limb (increased flexion from 64ms to 168ms post IC 20), and frontal plane ankle motion on the involved limb greater inversion from 96ms pre-IC to 15ms post-IC).
Doherty et all. 2016 (A)	28 CAI (17M and 11W; A 23.2 ± 4.9 y; W 75.5 ± 13.9 kg; Height 1.7 ± 0.1 m; Cait 22.3; Faam 95.7 Faam-s 85.5)	42 COPERS (26M and 16W; A 22.7 ± 1.7y; W 73.4 ± 11.3 kg; H 1.7 ± 0.1 m; Cait 27.9; Faam 98.0 Faam-s 90.6)	3 single-leg drop land (DL) task on both their injured and non-injured limbs from a 0.4-m platform. Time-averaged 3-dimensional angular displacement profiles for the hip, knee and ankle joints were calculated in the time window from 200 ms pre-IC to 200 ms post-IC for a single DL trial.	Time-averaged 3-dimensional kinematic and kinetic profiles revealed that the CAI group displayed altered movement and joint moment patterns in the sagittal plane for the hip (increased flexion from 148ms pre-IC to 4ms post IC).
Doherty et all. 2016 (B)	82 participants (54M e 28W, 22.78 (21.89-23.67) years, 76.6 (73.66-79.54) kg, 1.72 (1.70-1.74) m).		Participants in the LAS cohort were evaluated al 3 time points: within 2 weeks of injury (time point1), 6 months after injury (time point2), and then 12 months (time point3). Complete a protocol of 5 movement tasks, one of interest for us, single leg drop jump.	Only 70 partecipants arrived at 1 year follow-up). No biomechanical data
Hock et all. 2015	15 CAI (5 men, 10 women; age = 21.9 +/- 2.1 years, height = 168.7 +/- 9.0 cm, mass = 69.4 +/- 13.3 kg).		5 single legged drop landing task, participants stood on a 40-cm box and to drop onto the force plate located 10 cm in front of the box. Kinematics for the ankle, knee, and hip were observed at initial contact, maximum angle, and total displacement in the sagittal plane. We also summed the sagittal-plane	Kinematic variables: At Initial contact Ankle platar flexion was 26.24° +/- 7.70, Knee flexion was 13.21 +/- 5.35, Hip flexion was 6.39 +/- 6.96. At maximum angle ankle dorsiflexion was 18.48 +/- 6.49, knee flexion was 56.11 +/- 12.06, hip flexion was 22.56 +/- 11.23. Sagittal-plane displacement of ankle was 44.73 +/- 8.77, knee was 42.90 +/- 9.11, hip was 16.16 +/-

			displacements.	9.81, total was 103.79 +/- 23.77.
Koshino et all. 2016		18(9M,9F) Mean ± (SD) Age, y 21.7 ± 0.8 Height, m 1.64.5 ± 0.63 Weight, kg 54.2 ± 6.9	3 single leg jumps from a height of 30 cm into a force plait. Inversion angle at IC was measured. The toe in direction was represented as a positive angle.	Inversion angle at IC (°) -5.1 ± 6.5
Lee et all. 2018		27 (19M, 8F) Age, y 21.4 ± 1.8 Height, m 1.71 ± 0.08 Weight, kg 66.8 ± 12.1	2 single leg jumps from a height of 30cm into a force plait. The joint angle at IC, joint ROM, for the ankle, knee and hip joints of the dominant leg during the landing phase were obtained.	Ankle Initial contact: - Mean ± SD −11.5 ± 13.1°, - Ranged from −27.8° to 27.8 Maximum dorsiflexion angle: - Mean ± SD −27.7 ± 4.6 Ankle ROM (degree): - Mean ± SD 42.9 ± 12.7 Knee ROM (degree): - Mean ± SD 40.6 ± 5.8 Hip ROM (degree): - Mean ± SD 21.6 ± 5.8
Madigan et all. 2003		12M Mean ± (SD) Age, y 27.9 ± 5.4 Height, m 1.856 ± 0.05 Weight, kg 93.3 ± 9.7 kg	2 single-leg drop landing from a height of 25cm into a platform placed 33 cm away from the box. The measured kinematic variables included joint angles at impact and maximum joint flexions during landing.	Hip flexion at impact (°) 19.4 ± 8.6 Knee flexion at impact 8.5 ± 5.1 Ankle flexion at impact (d-flex) 32.0 ± 5.2 Hip flexion maximum (°) 29.0 ± 11.3 Knee flexion maximum 42.6 ± 7.1 Ankle flexion maximum (d-flex) 13.3 ± 3.9
Moisan et all. 2019	32 CAI. 18<x<45 years.	31 Control subjects. 18<x<45 years.	4 tasks were completed in a random order across participants, 1 of interest for us, 5 UNILATERAL DROP LANDING (DROP): the participants had to stand on a 46 cm high platform, drop onto a force plate, and stay in balance on the landing surface for two seconds. Joint angles and	For the DROP task, No between-group difference was observed for all joint angles and moments.

			moments were normalised to 0 to 100% of the landing phase from the initial contact to the maximal knee flexion.	
Pionnier et all. 2014	10 CAI group (7 men, 3 women; age = 26.1 +/- 5.7 years; height = 1.75 +/- 0.10 m; mass = 73.9 +/- 14.5 kg, FAAM adl 93.7 +/- 3.6 and sport85.9 +/- 7.7)	10 CONTROL subjects (7 men, 3 women; age = 27.3 +/- 10.3 years; height = 1.79 +/- 0.06 m; mass = 71.6 +/- 11.3 kg, 100% on FAAM and FAAM Sports)	Falling from a from a 15 cm high to a force platform. They were asked to maintain balance during 20 seconds after the unipodal landing. Joint kinematics was analysed from 0.2 seconds before FS to 0.2 seconds after FS.	Results between each lower limb of CAI participants did not highlight any difference. Ankles of CAI participants were significantly less plantarflexed than CTRL ankles at 0.14 s before FS, and less adducted from 0.17 to 0.12 s before FS; CAI midfoot was significantly more abducted than CTRL from 0.20 before FS to 0.05 s after it; this result is also found at FS. Regarding rearfoot, dorsiflexion was significantly greater for CAI limbs than CTRL ones from 0.19 s before FS to 0.02 s after FS and from 0.08 to 0.16 s after it.
Terada et all. 2015	19 participants with self-reported CAI (11M and 8W, A 21.68 ± 4.82y, W 75.33 ± 14.81kg, H 171.82 ± 9.30, Faam 87.98 ± 6.80, Faam-s 75.48 ± 10.17 AII 5.58 ± 0.97)	CONTROL group included 19 participants (6M and 13W, A 20.58 ± 2.32, W 71.30 ± 15.37kg, H 168.05 ± 9.55cm, Faam and Faam-s 100.00, AII 0.00)	10 single-leg drop landing from a 30 cm high box that was placed at a distance equal to the participant's leg length away from the centre of the force plate: they jump down off on the centre of the force plate and attempt to obtain a single-leg balance position as fast as possible and maintain the position for 5s. They performed the drop landing under two separate conditions: looking-down and focused their vision on the force plate or	Participants with CAI showed decreased hip flexion 100 ms prior to IC compared to control participants. CAI subjects demonstrated decreased hip and knee flexion at IC compared to healthy participants in both conditions. No other significatcant variables between group or conditions. Sagital Plan Frontal plan HIP CAI LU 21.73+/-5.07* 8.16+/-6.51 LD 21.66+/-5.64* 7.37+/-7.26 CN LU 26.68+/-9.27 6.16+/-7.24 LD 27.79+/-10.06 5.62+/-7.61

			looking-up and read a random number that flashed on a computer monitor. Sagittal- and frontal-plane kinematics at the hip, knee and ankle joints were calculated at 100 ms pre-IC and IC.	KNEE CAI LU 5.82+/-3.58* -1.00+/-6.46 LD 5.85+/-3.35* -0.97+/-6.61 CN LU 9.46+/-7.18 0.23+/-6.46 LD 9.91+/-7.71 -0.27+/-5.37 ANKLE CAI LU 46.41+/-9.62 11.23+/-15.38 LD 45.87+/-10.57 11.29+/-15.80 CN LU 45.77+/-12.11 12.51+/-9.35 LD 45.44+/-12.25 12.75+/-10.18
Wright et all. 2016	23 FAI (12 M e 11 W, A: 23.30+/-3.84y, H: 1.71+/-0.11 m W:68.66+/-14.60kg, CAIT: 20.52+/-2.94)	23 COPER (12 M e 11 W, A: 23.52 +/-3.68y, H: 1.72+/0.07m, W: 69.57+/-13.94kg, CAIT 27.74+/-1.69) 23 CONTROL (12 M e 11 W, A: 23.17+/-4.01y, H: 1.72 +/-0.08m, W: 68.78+/-13.26kg, CAIT: 28.78+/-1.78)	10 single-legged drop jumps: the participants step off a 40-cm box onto a force plate and then balanced on the involved leg for at least 10 seconds. Kinematic data for the forefoot angle (f. relative to h.) and hindfoot angle (h. relative to tibia) were calculated in the sagittal and frontal planes at IC and vGRFmax of each jump landing.	Sagittal plane: For the forefoot the groups were different at IC. A trend toward increased dorsiflexion in the coper (fpl7.94+/-0.82) group compared with the FAI (fpl 10.32+/-0.82) and control (fpl10.69+/-0.82) groups was evident, with medium effect sizes. For the hindfoot, a group difference was observed at IC. Specifically, individuals with FAI (fpl10.08+/-0.77) were more dorsiflexed than the coper (fpl13.26+/-0.77) or control (fpl13.51+/-0.77) groups, with strong effect sizes. Frontal plane: For both the hindfoot (inv FAI 7.81+/-1.08 CP 6.67+/-1.08 CN 8.54+/-1.08) and forefoot (ev FAI 4.58+/-0.52 CP 5.41+/-0.52 CN 5.79+/-0.52) in the frontal plane no group differences were apparent at IC. No group differences in neither forefoot or hindfoot nor sagittal-plane o frontal-plane motion at vGRF max.

Table 6

The articles considered cover a period of time from 2002 to 2019, while the type of studies is only observational. The population under investigation is composed of 830 subjects, 411 of which CAI, 138 Coper, 281 Healthy. As for the CAI population, 6 articles[9,14,22,29,34,38] completely fulfill the inclusion criteria with those of reference[18], while the remaining 6 articles which analyze a population with ankle instability[4,6,10,11,12,31] show 1 or more differences. Among the studies, 5 evaluate only the healthy subject[2,3,19,24,26], 1 only the CAI subject[22], 7 evaluate the CAI group in comparison with the healthy subject[4,6,10,12,29,31,34], 1 compares CAI with Coper[14], 2 compare CAI with both Coper and healthy subject[9,38], 1 follows a group of subjects injured up to one year after the event[11]. As for the intervention 1 study tests subject to step down and single leg drop jump from 32 cm in height[4], 1 only to step down from 15 cm[31], 15 to single leg drop jump of which 1 from 46 cm[29], 7 from 40 cm[6,9, 11,12,14,22,38], 1 from 35 cm[10], 3 from 30 cm[19,24,34], 1 from 25 cm[26] and finally 2 from 20, 40 and 60 cm[2,3]; in all these studies the subjects had to land immediately in front of the box, with the exception of 5 studies in which the subjects had to jump forward and reach a platform positioned in 1 study at 33 cm[26] of distance, in 1 at 30 cm[2], in 1 at 20cm[3] , in 1 at 10 cm[22], in 1 at a distance proportional to the subject's leg[34] length. The setting in all studies is represented by the laboratory. The primary outcome considered for all the studies is the kinematics, in terms of joint angles in the different landing phases. The ankle data are analyzed in all the studies, in 13 articles also those of the knee[2,3,4,6, 10,11,12,14,22,24,26,29,34] and in 10 articles those of the hip[2,3,10,11,12,14,22,24,26,34]. Instead, the angular planes considered, the methods to detect them, the position of the markers in the different parts of the body, as well as the temporal and spatial references to identify the different landing phases vary from study to study. These differences are displayed in Table 6. Table 7 deepens the position of the markers for each study.

Title	Marker Position
Ali et all. 2014 (A)	Customised marker set adapted from Oxford Metrics Plug-in-gait marker placement document.
Ali et all. 2014 (B)	Retro-reflective markers were placed on subjects' body using a customized version of the Vicon Plug-in Gait marker set via double-sided tape. The Vicon Plug-in Gait marker set was customized to include additional markers at the hip and medial aspects of the elbow, knee and ankle, as well as additional foot markers. In addition, different marker locations were also used at the proximal ends of the pelvis.
Brown et all. 2008	The lateral femur sensor was attached over the iliotibial band midway between the hip joint and the knee joint. The tibial sensor was placed on the anterio-medial portion of the tibia, 3–5 cm distal to the tibial tuberosity, and the calcaneal sensor was placed on the most inferior portion of the bone on the midline of the shank. The foot sensor was placed between the 2nd–3rd metatarsals, at the midpoint of the metatarsals. A sensor was also placed on the sacrum between the posterior supe- rior iliac spines.
Caulfield et all. 2002	Reflective markers were placed on the greater trochanter, the knee joint, the lateral malleolus and the head of the fifth metatarsal.
De Ridder et all. 2015	Reflective surface markers were placed on anatomical landmarks according to the Ghent Foot Model. This six-segment model tracked the shank, rear foot, midfoot, medial and lateral forefoot and the hallux as individual

	functional segments. The single-segment foot was defined by markers on the calcaneus, the lateral malleolus and the head of the first and fifth metatarsal head.
Delahunt et all. 2006	Markers were placed on the lateral aspect of the knee joint line, the lateral malleolus, the heel, and the fifth metatarsal head. Wands with anterior and posterior markers were positioned on the pelvis, sacrum, thigh, and shank.
Doherty et all. 2015	Marker positions within a Cartesian frame
Doherty et all. 2016 (A)	Marker positions within a Cartesian frame
Doherty et all. 2016 (B)	No descriptions.
Hock et all. 2015	Applying retroreflective markers bilaterally on: acromioclavicular joint, anterior-superior iliac spine, posterior-superior iliac spine, iliac crest, greater trochanter, lateral and medial femoral condyles, lateral and medial malleoli, base of the fifth metatarsal, and base of the first metatarsophalangeal joint.
Koshino et all. 2016	Modified Helen Hays marker sets with 25 retroreflective markers attached to the skin of the lower limbs (the sacrum, bilateral anterior superior iliac spines, greater trochanters, lateral thighs, lateral and medial femoral epicondyles, lateral shanks, lateral and medial malleoli, posterior heels and first, second and fifth metatarsal heads)
Lee et all. 2018	Retroreflective markers attached on bilateral anterior superior iliac spines, sacrum, greater trochanter, midpoint of the femur, lateral and medial epicondyles of the femur, lateral and medial plateaus of the tibia, midpoint of the tibia, lateral and medial malleoli, the calcaneus, and the first and fifth metatarsal heads.
Madigan et all. 2003	Motion sensors were placed on the head, torso, sacrum, right thigh, right shank, right foot, and left shank.
Moisan et all. 2019	Markers were attached on the bilateral anterior superior iliac spines, bilateral posterior superior iliac spines, greater trochanter, lateral and medial femoral epicondyles, fibular head, tibial tuberosity, medial and lateral malleoli, proximal posterior surface of calcaneus, distal attachment of the Achilles' tendon, sustentaculum tali and fibular tubercle.
Pionnier et all. 2014	Foot and ankle complex were divided into three parts, thanks to markers placement (no more descriptions).
Terada et all. 2015	Electromagnetic sensors were placed over the base of the sacrum, mid-lateral aspect of the femur, anterior aspect of the tibia and dorsum of the foot (mid-shaft of the second and third metatarsals).
Wright et all. 2016	Marker plates were attached to the posterior pelvis at the height of the posterior-superior iliac spine and bilaterally on the distal thigh and shank. Anatomical markers were placed bilaterally on the greater trochanters, anterior-superior iliac spines, lateral and medial femoral epicondyles, lateral and medial malleoli, proximal and distal fifth metatarsals, distal second metatarsal, proximal and distal first metatarsals,

	and lateral, medial, posterior-superior, and posterior-inferior calcaneus. Then were removed the calibration-only markers (ie, bilateral greater trochanter, lateral and medial femoral epicondyles, medial malleolus, and posterior-superior calcaneus).

Table 7

As for the results, in order to be able to summarize and present the data arisen from the articles, it was decided to expose them by comparing first the CAI subjects with the Healthy ones, then the CAI in comparison with Coper.

CAI vs healthy comparison

The data arisen from the articles comparing these two types of subjects were divided both by joint (ankle, knee and hip) both by the three landing phases (the phase preceding the initial contact Pre IC, the initial contact phase IC and the following one, or Post IC). These data are summarized in Table 8.

PRE IC

As for the ankle the CAI population compared to healthy one shows: in 1 article more inversion[10], in 2 articles more dorsiflexion[6,31], in 2 articles less inversion[12,31] and in 1 article more midfoot eversion and more rearfoot dorsiflexion[31]. In 3 articles there was no difference in sagittal plane[10,12, 34] and in 1 article in the frontal plane [34].

As for the knee, the CAI population compared to the healthy one shows: in 1 article more flexion[6], in 2 articles no difference in the sagittal plane[12.34], in 2 articles no difference in the frontal plane[12.34].

Analyzing the hip, the CAI population compared to healthy people shows: in 1 article less flexion[34], in 1 article less extrarotation[10], in 2 articles no difference in the frontal plane[12,34], in 1 article no difference in the sagittal and transversal plane[12].

IC

As for the ankle, the CAI population compared to healthy one shows: in 1 article more dorsiflexion of the hind foot[38], in 2 articles more dorsiflexion[6,9], in 1 article less inversion[12], in 1 article more eversion, more eversion of the midfoot and more dorsiflexion of the rearfoot[31], in 3 articles no differences in the frontal plane are detected[10,34,38], in 4 articles no differences in the sagittal plane are detected[10,12,29,34], 1 article does not detect differences in the sagittal plane for the forefoot[38].

As for the knee, the CAI population compared to the healthy one shows: in 1 article more flexion[6], in 1 article less flexion[34] and therefore more extension, in 2 articles no difference in the frontal plane[12.34], in 2 articles no difference in the sagittal plane[12.29].

Concerning the hip, the CAI population compared to healthy one shows: in 1 article less flexion[34], in 1 article more flexion[12] in 2 articles no difference in the frontal plane[12,34] and in 1 article no difference in the transversal plane[12].

POST IC

As for the ankle, the CAI population compared to the healthy one shows: in 1 article less dorsiflexion[10], in 1 article more dorsiflexion[6], in 1 article less inversion[12], in 1 article more eversion of the midfoot and more dorsiflexion of the rearfoot[31], in 1 article not differences are detected in the frontal plane[10], in 2 articles no difference in the sagittal plane[12,29].

As for the knee, the CAI population compared to the healthy one shows: in 1 article more flexion[6], in 1 article more flexion in the contralateral knee[12], in 2 articles no difference in the sagittal plane[12,29], in 1 article no difference in the frontal plane[12].

As for the hip, the CAI population compared to the healthy one shows: in 1 article more bilateral flexion and no difference in the frontal and transversal plane[12].

	Pre IC	IC	Post IC
Ankle	+ inversion[10] + dorsiflex[6,31] - inversion[12,31] + eversion midfoot[31] + dorsiflex rearfoot[31] no difference sagittal plane[10,12,34] no difference frontal plane[34]	+ dorsiflex hindfoot[38] + dorsiflex[6,9] - inversion[12] + eversion[31] + eversion midfoot[31] + dorsiflex rearfoot[31] no difference sagittal plane[10,12,29,34] no difference frontal plane[10,34,38] no difference sagittal plane forefoot[38]	-dorsiflex[10] +dorsiflex[6] -inversion[12] +eversion midfoot[31] +dorsiflex rearfoot[31] no difference frontal plane[10] no difference sagittal plane[12,29]
Knee	+ flex[6] no difference frontal plane[12,34] no difference sagittal plane[12,34]	+flex[6] -flex[34] no difference sagittal plane[12,29] no difference frontal plane[12,34]	+flex[6] +flex controlateral knee[12] no difference sagittal plane[12,29] no difference frontal plane[12]
Hip	-flex[34] +flex[12] -extra[10] no difference frontal plane[12,34] no difference transversal plane[12]	-flex[34] +flex[14] no difference frontal plane[12,34] no difference sagittal plane[12] no difference transversal plane[12]	+flex bilateral hip[12] no difference frontal plane[12] no difference transversal plane[12]

Table 8

In 2 articles, CAI subjects show minor angular displacement in the sagittal plane of the ankle [4,9].

CAI vs Coper comparison

The data arisen from articles comparing CAI subjects to Coper ones concern the ankle, knee and hip joint during the three phases (Pre-IC, IC, Post-IC). These data are summarised in Table 9.

PRE IC

As for the ankle, the CAI population in 1 article reports no difference in the sagittal and frontal plane[14.] compared to the Coper.

Also in relation to the knee, the CAI population compared to the Copers show in 1 article the lack of difference in the sagittal and frontal plane[14].

As for the hip, the CAI population compared to Copers one shows in 1 article more flexion and no difference in the transverse and frontal plane[14].

IC

As for the ankle, the CAI population compared to the Coper one shows: in 1 article greater dorsiflexion and no difference in the frontal plane[4], in another article less dorsiflexion of the forefoot, more dorsiflexion of the hindfoot and no difference in the frontal plane of both the forefoot and hindfoot[38].

In the analysis of knee data, the CAI population compared to Coper one shows: in 1 article no difference in the sagittal and frontal plane[14].

As for the hip, the CAI population compared to Coper one shows: in 1 article more flexion and no difference in the frontal and transversal plane[14].

POST IC

As for the ankle and knee, the CAI population compared to the Copers one shows: in 1 article no difference in the sagittal and frontal plane[14].

As for the hip CAI population compared to the Coper one shows more flexion in 1 article, while no difference in the frontal and transverse plan[14].

	Pre IC	IC	Post IC
Ankle	no difference in frontal and sagittal plane[14]	+ dorsiflex[4] - Dorisflex forefoot[38] + dorsiflex hindfoot[38] no difference in frontal plane[4] no difference in hindfoot and forefoot frontal plane[38]	no difference in frontal and sagittal plane[14]
Knee	no difference in frontal and sagittal plane[14]	no difference in frontal and sagittal plane[4,14]	no difference in frontal and sagittal plane[14]
Hip	+flex[14] no difference in frontal and transversal plane[14]	+ flex[14] no difference in frontal and transversal plane[14]	+flex[14] no difference in frontal and transversal plane[14]

Table 9

In an article, CAI subjects compared to Copers ones show less sagittal ankle displacement, greater displacement in the frontal plane during the step down and greater maximum eversion and less displacement in the sagittal ankle plane during the drop jump[4]. An article shows for CAI subjects greater ROM in inversion / eversion of the midfoot compared to Copers ones and less ROM for Copers in the sagittal plane of the lateral and medial forefoot[9].

	Item N°	Ali 2014 (A)	Ali 2014 (B)	Brown 2008	Caulfield 2002	De Ridder 2015	Delahunt 2006	Doherty 2015	Doherty 2016(A)	Doherty 2016 (B)	Hoch 2015	Koshino 2016	Lee 2018	Madigan 2003	Moisan 2019	Pionnier 2014	Terada 2015	Wright 2016
Title and abstract	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	0	1	1
Introduction																		
Background/rationale	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Objectives	3	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1
Methods																		
Study design	4	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	1	0
Setting	5	1	1	0	1	0	1	1	1	1	1	1	1	1	1	0	1	1
Participants	6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Variables	7	0	1	1	1	1	1	0	1	1	0	1	0	1	1	0	1	1
Data sources/ measurement	8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Bias	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Study size	10	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Quantitative variables	11	0	1	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1
Statistical methods	12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
Results																		
Participants	13	1	1	0	1	1	1	0	1	1	1	1	1	1	0	0	1	1
Descriptive data	14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Outcome data	15	1	1	1	1	0	0	0	0	0	1	1	1	1	0	0	1	1
Main results	16	1	1	1	1	1	0	0	0	1	1	1	1	1	0	0	1	1
Other analyses	17	1	0	1	0	1	0	1	0	1	1	1	1	1	1	0	1	1
Discussion																		
Key results	18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Limitations	19	1	1	1	0	1	1	0	1	1	1	1	1	1	1	0	1	1
Interpretation	20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Generalisability	21	1	1	0	0	0	1	0	0	0	0	1	1	1	0	0	0	0
Other information																		
Funding	22	0	1	1	1	0	1	0	1	1	0	0	0	1	1	0	1	0
Tot		16	18	16	14	14	15	11	15	18	16	19	16	18	14	6	18	18
%		73	82	73	64	64	68	50	68	82	73	86	73	82	64	27	82	82

Table 9

The bias risk assessment of the included articles is displayed in Table 9 that shows the score for each item for each study. From this analysis it is observed that, 6 articles have scores that refer to a low risk of bias[3,11,19,26,34,38] , 9 to a moderate risk of bias[2,4,6,9,10,14,22 , 24,29] and 2 with a serious risk of bias[12,31].

5. DISCUSSION

Overall, it is possible to affirm that the evidence is not sufficiently strong to express hypothesis concerning the difference between landing kinematics of a CAI subject and a healthy one, especially because of the high heterogeneity in the population, in some characteristics of the task, in the detection methods of the outcome and, lastly, in the results. As shown in results section, only three articles[14,22,29] refer explicitly to CAI criteria, today considered as a reference for this population, whereas other three [9,34,38] satisfy those criteria without making explicit reference, despite the fact that they do not express the time elapsed since the first injury clearly, even if it is possible to imply that it is more than a year. The remaining studies show different characteristics in some aspects: for example, two studies[6,10] are about Functional Instability, so very sensitive and non-specific criteria; an article[4] shows a distinction between Mechanical and Functional ankle instability, difference no longer recognize; another article[31] with serious risk of bias considers subjects with ankle instability and with a first episode dating back to at least four months, one[12] at six months (timeline still mistakable with sequels of an acute episode of LAS), and, at least, an article[11] is about a follow up of the participants from two weeks post-injury to an year, where it is actually possible to talk about CAI. Another difference is that the most dated articles [6,10,31] do not provide an administration of questionnaires concerning functionality in the selection of participants yet. As for the studies that analyze healthy population[2,3,19,24,26], in other words the controls, it is possible to observe a major homogeneity in population characteristics, such as personal data (age, weight and height) and level of sporting activity of subjects. Closing these considerations, it is possible to affirm that, despite the fact that all the subjects have characteristics of chronic ankle instability, there are some differences that do not allow full concordance and homogeneity in the population, so it is impossible to compare them with healthy subjects. Considering the task, despite the choice of including only articles about single leg drop jump test led to a homogeneity in the analyzed movement, the heights from which these tasks are realized are different among them, as it is possible to see in the results paragraph. Even though eleven out of seventeen articles [4,6,9,10,11,12,14,19,22,24,34,38] foresaw a jump from a height between 30 and 40 cm and considering that in these situations the height difference does not influence the landing kinematics, several are the considerations for the remaining five articles [2,3,26,29,31] that show variable heights from 15 to 60 cm. The same reasoning is valid if it is considered the jump length: in twelve articles it finishes immediately in front of the box, in other four articles [2,3,22,26] the landing platform is at a distance of 10 to 33 cm and in one[34] the distance is proportional to the leg length of participants, implying, as a consequence, a “forward jump”, whereas in other studies it was rather a “drop down” or “step off”. According to some articles [3,8,20] and considering the fact that at different jump modality in terms of departure height and arrival distance corresponds a different landing kinematics, it is difficult to obtain a homogeneity that permits to consider comparable the data of the different studies. Considering the outcome and its detection methods, it is possible to notice some considerations. First of all, in each study researchers used a different markers displacement on body segments of participants, showing in this way a great variability of the calculation of joint angles. In fact, although the most frequently used points for the markers placement are the lateral[6,9,10,19,22, 24,29,38] or medial [19,22,24,29] malleolus, the calcaneus [4,9,10,19,24,29,38], the first [9,19,22,24,38], the second and the third [4,19,34,38], or the fifth metatarsal [6,9,10,19,2224,38], these points not only are not used in all the studies, but they also change their anatomical localization (i.e. base or metatarsal head, posterior, lateral or medial aspect of the calcaneus) and they are put in correlations with different markers, diversifying in this way the detection of the angles. An interesting consideration is the will to consider the foot not as a single rigid segment, as in the majority of the analysed articles, but as a multi-segment foot model, as it is proposed in 3 articles [9,31,38]. In this way, it is possible to take into account all the small joints that contribute to the foot and ankle biomechanics. As a result, a more truthful analysis of the whole district kinematics can be given. In addition to several methods for measuring joint angles it is important not to forget, as it is said in the previous chapter, that each author decides to consider different movement planes and number of joints without considering a way to support their different choices. Furthermore, if it is examined the aspect of space and time references during the landing phase, fifteen out of seventeen articles consider the initial contact as a pression (detected thanks to power platforms) of 10 N exerted by the foot during the landing phase, whereas two other articles (9,31) have the 15 N as a reference: in this way, the initial time of contact corresponds to two different landing instants. However, the major difference occurs when the considerations are about the time immediately before and after impact phase; only five [10,11,12,14,31] articles consider the 200ms before and after IC, whereas the remaining articles refer to IC and maximum ankle dorsiflexion [9] or knee flexion [29], or to vertical ground reaction maximal force [38] as final landing phases, or they consider only the 100 ms pre-IC up to IC [34] . This leads to the conclusion that it exists another important heterogeneity among all the strategies to investigate outcomes among the studies. Taking into account the above and the previous results section, it is impossible to perform a statistical analysis of the submitted data. It is very difficult to obtain a synthesis and some conclusions from the results presented in Table 7 and 8. If the analysis was restricted only to those studies that adhere to CAI reference criteria, that examine the single leg drop jump from similar heights and close to 40 cm and with low or moderate bias risk, it would show that two articles [14,29] with moderate bias risk and another one [34] with low bias risk affirm that there is no difference among CAI and healthy subjects if it is considered the ankle kinematics in landing , while other two studies, one [9] with moderate bias risk and the other [38] with low bias risk, it is detectable a position in greater dorsiflexion at initial contact. Relatively to the knee, a study [34] finds a major extension to IC, other 2 studies [9,14] do not find any differences, another one [14] finds a major hip flexion during the pre-phase, to IC and immediately after, and in the last one [34] there is a major extension to IC. So, if a sub-sample with the most homogeneous and optimal characteristics possible was analyzed, data would be contradictory and would not be useful for a hypothesis formulation. By comparing these results with the current literature, a review [32], that compares healthy and CAI subjects subjected to unilateral landing task, finds some differences in the lower limb kinematics in the sagittal plane, in particular a major ankle dorsiflexion at the time of impact, a lower total ROM of this articulation and a different position of knee and hip depending on the task of CAI subjects compared to healthy ones. This study shows some differences in materials and methods if compared to ours. In other words, it does not specify the CAI reference criteria and it includes different types of task in the analysis (in particular single leg drop jump and stop jump). This fact affects the kinematics of participants, as it is also indicated by the results, and the comparability of data is compromised, because different tasks correspond to different kinematics [8]. Another research [35] analyses the same topic, the CAI influence on the lower limb kinematics during landing task, but with a particular attention to the knee and to its possible implications in terms of injuries. It is said that, while the ankle results are too contrasting to reach conclusions and for the hip there are no differences, the knee lands with less bending, that has shown to be key risk factor in non-contact knee injuries. In this article, in addition to task heterogeneity (the majority of the studies deal with single leg drop jump and single leg jump), the CAI inclusion criteria allow the inclusion of studies with patients who suffer from a lesion which is older than 4 months. The problem is that this criterion includes patients with symptoms confusingly similar to the results of an acute LAS [18] and it is not possible to classify them as chronic, undermining, in this way, the premises of the study. Another interesting point comes from an article [22] with moderate bias risk, it affirms that the ROM in dorsiflexion, which is statically measured with the weight-bearing-lunge test and dynamically during the initial contact of the single leg drop jump test, is strongly related to knee and hip kinematics on the sagittal plane while landing from a jump in CAI subjects. According to this article, persons with less dorsiflexion rom exhibited a less flexed landing strategy that attenuated ground reaction forces less efficiently. Moreover, CAI subjects very often show limitations in dorsiflexion [23]. In this regard, WLBT could be a rapid and easy test to take into account by health professionals in clinical practice in order to identify those subjects who present the already mentioned alterations during the landing dynamic [22] because they have a major overloads and accidents risk [1]. The correlation between the reduction of ankle dorsiflexion and the alteration of lower limb kinematics during a jump has also been reported by a recent review [27]. It analyses healthy subjects, but it can not find a conclusion on the characteristics of these alterations. One last interesting point emerges from a study with low bias risk [11]. It follows and examines the same subjects at 2 weeks, 6 and 12 months from the first LAS episode and it highlights that those subjects who were not able to do the single leg drop jump at 2 weeks from the injury, were the same that would have developed the CAI at a year, showing the inability to perform this task as a risk factor for the disease. To sum up, the study limits are: the too diversified inclusion criteria within the study population, the different modalities of outcome description and detection and some task characteristics. Concerning this last element, it must not be forgotten that a test performed in a laboratory is very different from a sport specific movement performed in an environment with much more external stimuli such as other players or different grounds. Therefore, it is very difficult to compare them. Furthermore, the execution of a gesture, especially if repeated in sequence, goes easily towards learning and/or fatigue, and this can misrepresent the performance. Another limit of the study is that it analyses only observational studies, which are qualitatively inferior in the context of primary studies. Finally, acknowledged the many already mentioned heterogeneities, the typologies of the studies drawing and considered the different degree of bias risk among the revision articles, it has not been possible to create a meta-analysis, because any numerical synthesis would be meaningless.

6. CONCLUSION

In conclusion, the evidence is not sufficiently strong to express hypothesis concerning the difference between the ankle kinematics and, more in general, the lower limb during the landing from a jump of a CAI subject compared to a healthy one. Future studies should include only trials with population who refer to CAI validated and well described in every single aspect criteria, they should analyze different tasks with parameters (height and distance) proportional to anthropometric ones of participants, they should use a markers displacement on standard body segments and they should take into account the mobility of the different foot joints. Furthermore, they should find an agreement on which kind of movement planes and joints number they should consider and which kind of temporal and physical references they should use in order to define the different phases of the landing of interest.

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