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L'influenza dell'arto superiore nella modifica dei parametri legati alla corsa: revisione della letteratura

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ABSTRACT

Introduction: Running and jogging is one of the most popular activities nowadays. Studies of human locomotion often focus on the lower extremity continuing to clarify the role of the lower limb in running providing practical implications for gait retraining programs. However even if arm swing is a distinctive characteristic of sprint running, with the arms working in a contralateral manner with the legs, the importance of arm action during running still remains unclear.

Given that evidence is limited on how arm contribution affects running, understanding and refining the role of the arm would seem important due to the potential to improve performance outcomes.

Objectives: The aim of this review is to improve understanding related to arm mechanics during running and try to find some practical implications that may be useful in clinical practice.

Methods: The review has been conducted and reported according to the Preferred Items for Systematic Reviews and Meta-analyses (PRISMA) checklist. A search strategy has been devised for each of the following electronic database: PUBMED, EMBASE, SCIENCE DIRECT, COCHRANE, PEDRO.

JBI Critical Appraisal Checklist for Analytical Cross-Sectional Studies has been used to assess the methodological quality of the included studies.

Results: The initial search yielded 2906 publications. Following the removal of duplicates, publications were filtered by reading the title and abstract leaving 15 potentially relevant papers, which were given full consideration. The search and inclusion process led to the selection of 4 articles that met the inclusion criteria.

According to the JBI checklist articles included had an overall good methodological quality. The aim of the authors was to determine how upper limb restriction can influence running parameters: one article tried to clarify the role of the scapula while the other three investigated the role of arm swing during running.

Conclusion: The results of this review allow to conclude for certain that running with arm restriction is different than running with typical arm swing, but there is no solid evidence that allow us to draw firm conclusions on how the upper limb can influence running parameters. This review sets the stage for new studies and can be an important starting point for future studies that should consider larger populations and more homogeneous interventions with common outcomes in order to generalize the data.

1. INTRODUCTION

Running and jogging has become more popular than ever in the last years, even due to the increased awareness of aerobic exercise to maintain a healthy lifestyle.

Proper running biomechanics involves synchronous movements of all the components of the kinetic chain.

Studies of human locomotion often focus on the lower extremity analyzing the effect of gait retraining programs on running biomechanics and running economy. A systematic literature review found a strong relationship between lower-limb strength and sprint running performance ([1]). However, the role of the upper limb has been minimally described.

Arm swing is a distinctive characteristic of sprint running with the arms working in a contralateral manner with the legs ([2]).

The importance of arm action during running has been an ongoing discussion among practitioners.

Because sprint running has distinctive phases (i.e., start, acceleration, and maximum velocity) and the body's position varies throughout them, it is quite likely that the role of the arms may change in accordance with these phases. Furthermore, in team sport events, different starting positions are used to optimize sprint performance, for example, a crouch start (American football, track and field running) or a standing start (soccer, rugby, and basketball) ([3]).

Many studies clarified the role of the lower limb in running providing practical information on how a gait retraining program can be useful in managing healthy and pathological runner: running with a forefoot strike pattern has been shown to reduce impact loading and can be an effective approach to reducing patellofemoral joint pain ([7]), running barefoot leads to changes such as less maximum vertical ground reaction forces, less extension moment and power absorption at the knee, less foot and ankle dorsiflexion at ground contact, less ground contact time, shorter stride length, increased stride frequency, and increased knee flexion at ground contact ([8]).

Given that evidence is limited on how arm contribution affects running, understanding and refining the role of the arm would seem important due to the potential to improve performance outcomes.

2. OBJECTIVES

The aim of this review is to improve understanding related to arm mechanics during running and try to find some practical implications that may be useful in clinical practice.

3. METHODS

3.1 Identification and selection of the literature

This review will be conducted and reported according to the Preferred Items for Systematic Reviews and Meta-analyses (PRISMA) checklist ([5]).

A search strategy will be devised for electronic database (PUBMED, EMBASE, SCIENCE DIRECT, COCHRANE, PEDRO), with restriction for English language. Due to the limited number of papers expected from the research, no date restrictions and publication type will be applied.

A preliminary search will be done on each database using keywords such as *running, jogging, upper limb,* and *upper extremity*. Keywords will be then associated with each other through the use of boolean operators AND-OR in order to obtain a more sensitive and specific search string.

The final search will be launched on September, 13 2022 involving the following search strategy:

- **PubMed** *(Running OR Jogging OR Running[Mesh]) AND ("Upper limb"[tiab] OR "upper extremity"[tiab] OR elbow[tiab] OR hand[tiab] OR shoulder[tiab] OR arm[tiab] OR forearm[tiab] OR "upper extremity"[MeSH Terms]) AND (biomechanic* OR motion OR Kinematic* OR kinetic* OR "human movement analysis" OR "gait measurement*" OR "motion analysis" OR "gait pattern*").*

- **Embase** (Running OR Jogging) AND ("Upper limb" OR "upper extremity" OR elbow OR hand OR shoulder OR arm OR forearm) AND ('biomechanics' OR motion OR 'kinematics' OR 'kinetics' OR "human movement analysis" OR "gait measurement" OR "motion analysis" OR "gait pattern")

- **Science Direct** (Running OR Jogging) AND ("Upper limb" OR "upper extremity" OR elbow OR hand OR shoulder OR arm OR forearm)

- **Cochrane** *(1) MeSH descriptor: [Running] explode all trees, (2) Running, (3)Runner, (4) Jogging, (5) 1 or 2 or 3 or 4, (6) "upper limb", (7) MeSH descriptor: [Upper Extremity] explode all trees, (8) 6 or 7, (9) 5 and 8.*

- **PEDro** *Running AND upper limb.*

Titles and abstracts of all identified citations will be screened by a single reviewer, with the full-text of articles meeting the initial inclusion criteria retrieved for further screening. Reference lists of all publications considered for inclusion will be further reviewed and a manual search will be conducted.

Rayyan, a software used to screen and select studies, will be used to manage records and data ([6]).

3.2 Selection criteria

An article will be considered eligible for inclusion if it meets all of the following criteria:

1. the study is written in English;
2. the full-text is available;
3. the article is a cross-sectional study
4. the population examined is made up of adults (age>18);
5. the protocol includes straight-line, submaximal running and sprinting (either on a treadmill or overground);
6. the outcome of interest is a biomechanical (kinetic, kinematic and/or spatiotemporal) intended to have a direct result on running parameters.

3.3 Exclusion criteria

Articles will be excluded if:

1. the full-text is not available;
2. the article is not a cross-sectional study
3. the study does not correlate the upper limb with biomechanical or physiological variables intended to have direct impact on running parameters;
4. the protocol only includes lateral, cutting or other modes of locomotion;
5. the study analyzes the influence of upper limb on other districts not directly involved with running.

3.4 Data items

The following data will be extracted: general characteristics of the studies included (e.g., study design), characteristics of the population included (e.g., age, sex, sport), any interventions and outcomes data (e.g., biomechanical or physiological variables intended to have a direct result on running parameters).

3.5 Assessment of methodological quality

JBI Critical Appraisal Checklist for Analytical Cross-Sectional Studies ([4]) will be used to assess the methodological quality of the included studies.

3.6 Data synthesis and analysis

Data will be synthesized in narrative formats and the studies' interventions characteristics will be tabulated by descriptive statistics. Biomechanical (kinetic, kinematic and/or spatiotemporal) or physiological variables intended to have a direct result on running parameters will be summarized according to the population and or intervention characteristics.

4. RESULTS

4.1 Study selection

Figure 1 provides a visual overview of the study selection process. Search results were imported into a published software ([6]) in order to manage records and data.
The initial search yielded 2906 publications. Following the removal of duplicates (n=192), publications were filtered by reading the title and abstract leaving 15 potentially relevant papers, which were given full consideration. These studies were considered in detail for appropriateness, resulting in a further 11 papers being excluded because they didn't meet the inclusion criteria.
The search and inclusion process led to the selection of 4 articles that met the inclusion criteria.

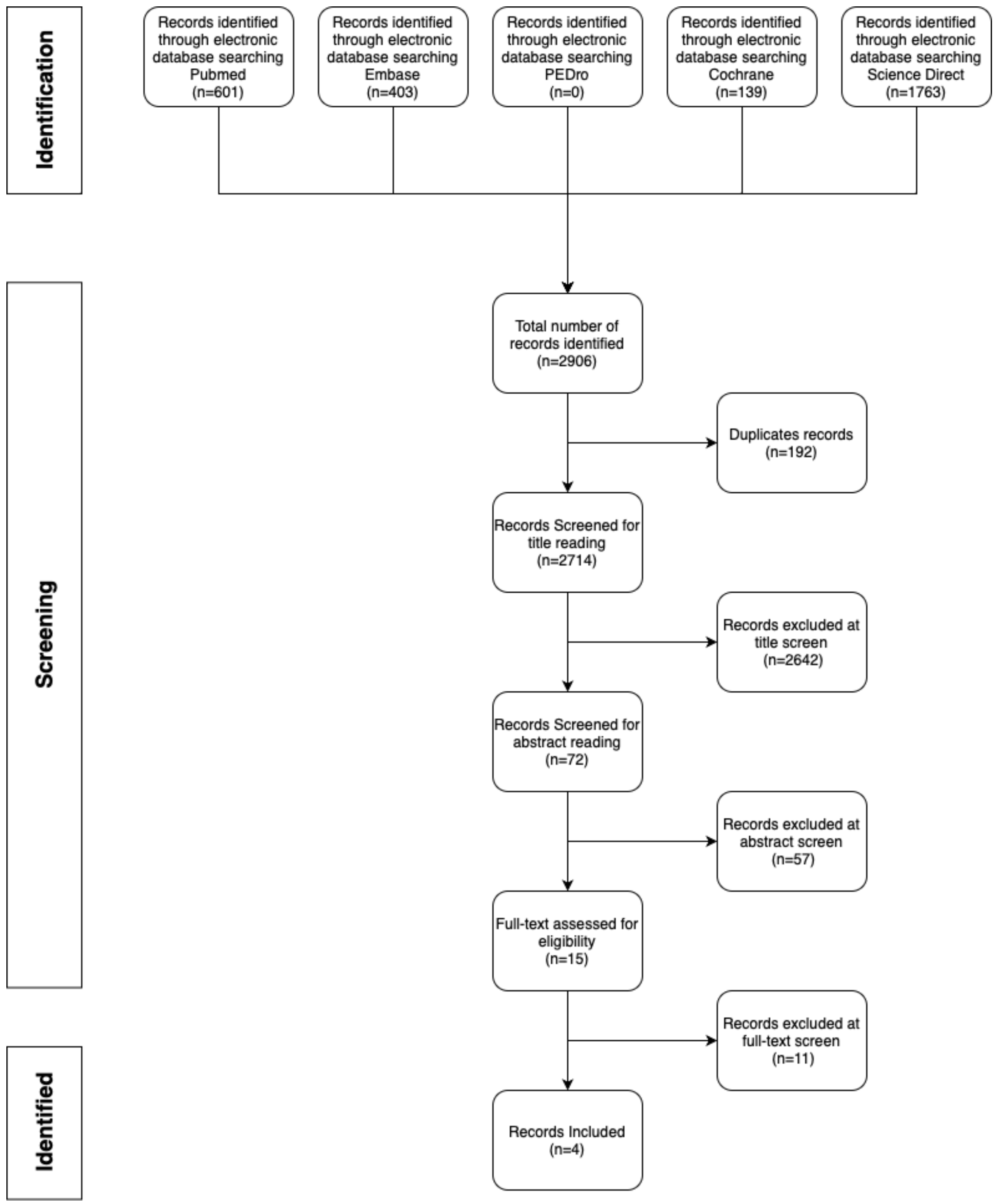

Figure 1 PRISMA flow diagram showing identification and selection of included studies

4.2 Study Characteristics

The 4 articles that met the inclusion criteria were all cross-sectional studies. The overall number of participants examined in the various studies is 49, aged between 18 and 45 years. All participants were in good health and sport-active: track and field athletes, team-sport athletes and other sports that included running activities.

The data and characteristics of the studies that emerged from the research are summarized and schematized in Table 1. In particular, the author and year of publication, the study design with related objectives, the characteristics of the population, the type of activity, the outcome measures used were highlighted and the main results of the various articles were summarized.

TABLE 1: SUMMARY OF THE STUDIES INCLUDED

Author	Study Design	Participants	Intervention/Control	Results/Outcome
C. Agresta et al. 2018 [9]	Cross sectional	**N=15** **8 males** (mean±SD: age = 28,4 ± 7,7 years, height = 180,4 ± 8,6 cm, Weight = 73,3 ± 13,4 kg) **7 females** (mean±SD: age = 29,3 ± 4,4 years, height = 165,5 ± 5,2 cm, Weight = 62,9 ± 6,9 kg)	Determine the influence of unilateral arm swing during running on lower extremity frontal and sagittal plane kinematics associated with sport and running-related injury. Participants ran at a self-selected, constant speed using: - typical arm swing, - one arm restrained (non dominant arm). - both arms restrained Whole-body kinematics were recorded during all running conditions using a six-camera passive marker system	Data from two participants were omitted. Differences in lower extremity mechanics between running with unilateral arm swing restriction and running with typical arm swing: - Foot strike angle decreased with unilateral arm swing restriction ($p < 0.05$) - Peak knee abduction angle ($p < 0.05$) and peak hip adduction angle ($p < 0.05$) increased - Vertical COM displacement ($p < 0.05$) decreased. - No significant differences in lower extremity kinematics were found between running with typical arm swing and running with bilateral arm swing restriction. - Stride time significantly decreased when running with unilateral arm swing motion compared to typical arm swing ($p < 0.05$) and with bilateral arm swing restriction compared to unilateral arm swing restriction ($p < 0.05$). - Stride length was significantly decreased during unilateral arm swing restriction compared to typical arm swing ($p < 0.05$). Stride length during running with bilateral arm swing restriction was decreased compared to unilateral arm swing restriction ($p < 0.05$) and typical arm swing ($p < 0.05$). - Stride frequency increased during unilateral arm swing restriction compared to typical arm swing ($p < 0.05$) and highest during bilateral arm swing restriction running compared to unilateral arm swing restriction ($p < 0.05$) or typical arm swing motion ($p < 0.05$).

Brooks LC et al. 2022 [10]	Cross-sectional	**N = 17** **10 males** **7 females** 5 males and 2 females (age: 22.0 ± 1.0 years, mass: 72.2 ± 9.9 kg, height: 1.77 ± 0.07 m) were former collegiate track and field (TF) athletes. 5 male and 5 female (age: 20.9 ± 2.2 years, mass: 74.3 ± 17.1 kg, height: 1.74 ± 0.11 m) were experienced team-sport (TS) athletes.	Determine the effects of restricting the arm motion on short sprint performance. Sprint performance was measured in 17 athletes during normal and restricted arm motion conditions. The TF participants performed four-point sprint starts, while the TS participants performed two-point standing starts. Instantaneous velocity was measured throughout each 30 m trial using a radar system.	- The 30 m times were faster for normal compared to the restricted arm conditions, but the between-condition difference was only 1.6% overall and < 0.10 s for the entire group (4.82 ± 0.46 s vs. 4.90 ± 0.46 s, respectively; $p < 0.001$) and both TF (4.55 ± 0.34 vs. 4.63 ± 0.32 s; $p < 0.001$) and TS subgroups (5.01 ± 0.46 vs. 5.08 ± 0.47 s; $p < 0.001$). - The authors concluded that restricting arm motion compromised short sprint running performance, but only marginally.

Miller RH et al. 2009 [11]	Cross-sectional	**N = 7** **4 males** **3 females** mean±SD: age = 28 ± 3 years, height = 177 ± 6 cm, mass = 73 ± 14 kg.	Determine the effects of suppressing arm swing on GRFs and lower extrem- ity kinematics during running. 3D stance phase, lower extremity joint angles and ground reaction forces (GRFs) were determined for seven subjects running in three different condition: - Condition N: running normally, with the arms unrestrained - Condition RC: running with the arms held across the chest - Condition RB: running with the arms held behind the back"	Compared with the normal condition: - when the arms were restrained across the chest RC, the lateral GRF peak increased by 6.3% bodyweight (BW) (p=0.005), and the second vertical GRF peak decreased by 12.8% BW (p = 0.0001). - when the arms were restrained behind the back RB, the second vertical GRF peak decreased by 9.7% BW (p=0.002). The only large effect size was for the difference in lateral GRF peaks between conditions N and RC (ES=1.02). - Changes in peak joint angles between conditions were reported but of the 18 joint angle peaks compared with condition N, six had large effect sizes: peak hip adduction, knee flexion, and knee adduction for condition RC, and peak hip internal rotation, knee flexion, and knee adduction for condition RB. - The duration of stance increased slightly (+12 ms on average) when comparing conditions RC and RB, there were no significant differences in any of the GRFs or joint angle peaks.

Otsuka M et al. 2016 [12]	Cross-sectional	**N= 10** **10 Males** (mean ± standard deviation (SD), age: 21.3 ± 1.1 years; height: 176.2 ± 6.0 cm; body mass: 69.3 ± 9.4 kg). **Sport**: soccer (n = 5), rugby (n = 2), basketball (n = 2), tennis (n = 1).	Clarify the role of the scapula in sports-active students in first accelerated running. The participants performed four 5-m dashes without and with the scapula constrained. The participants sprinted from the same comfortable standing position with maximal effort in each trial. A physiotherapist created the constraint condition by taping both scapulae symmetrically using non-elastic therapy tape.	- In the constraint condition the 2-m sprint time was significantly longer than that in the free condition. - At the instants of foot-contact and take-off during the first step, no significant difference in the humerothoracic flexion angle was seen between the two conditions. In contrast, at the instants of foot-contact and take-off during the first step, the humerothoracic extension angle in the constraint condition was significantly smaller than that in the free condition. - The forward leaning vector angle of center of mass during the first step was significantly greater than that in the constraint condition. Although no significant difference in hip extension and foot forward leaning angles was seen at the instant of foot contact during the first step between the two conditions, at the instant of take-off, the hip extension and foot forward leaning angles in the constraint condition were significantly smaller than those in the free condition.

4.3 Qualitative assesment

The quality assessment tool used is the JBI Critical Appraisal Checklist for Analytical Cross-Sectional Studies (Appendix A). The purpose of this appraisal is to assess the methodological quality of a study and to determine the extent to which a study has addressed the possibility of bias in its design, conduct and analysis.
The qualitative assessment results are summarized in Table 2.

TABLE 2: JBI Critical Appraisal Checklist for Cross-Sectional Studies

Articles	Were the criteria for inclusion in the sample clearly defined?	Were the study subjects and the setting described in detail?	Was the exposure measured in a valid and reliable way?	Were objective, standard criteria used for measure-ment of the condition?	Were confoun-ding factors identified?	Were strategies to deal with confounding factors stated?	Were the outcomes measured in a valid and reliable way?	Was appro-priate statistical analysis used?
Agresta C.[9]	yes	yes	yes	yes	no	no	yes	yes
Brooks LC[10]	yes	yes	yes	yes	yes	yes	yes	yes
Miller RH[11]	no	yes	yes	yes	no	no	yes	yes
Otsuka M[12]	unclear	yes	yes	yes	no	no	yes	yes

From the qualitative analysis emerges an overall good methodological quality of the studies included according to the JBI checklist items. Strategies to deal with confounding factors were not stated in any article except for the Brooks LC et al. 2022 ([10]) study. Criteria for inclusion were not described in the Miller RH et al. 2009 ([11]) article, while they were not clearly defined in Otsuka et al. 2016 ([12]) study.

5. DISCUSSION

The aim of this review was to improve understanding related to arm mechanics during running and try to find some practical implications that may be useful in clinical practice. As far as known, this is the first review on this topic.
The present literature is poor and inconsistent, the amount of article included, according to the search strategy adopted, is very small and heterogeneous in terms of interventions and outcomes.

5.1 Main findings

Agresta and colleagues ([9]) state that running with bilateral symmetry (i.e. running both arms swinging or no arms swinging) is more similar from a kinematic standpoint than running with an asymmetry (i.e. running with only one arm swinging).
These finding suggests that a large or enforced upper body asymmetry, as is the case in sports using hand-held equipment or ball carries, can influence the movement of the lower limb, altering some parameters correlated with some running injuries.
Significantly greater peak hip adduction angle and knee abduction angle during stance were found when running with unilateral arm swing restriction compared to either typical arm swing or bilateral arm swing restriction. Aberrant frontal plane knee and hip mechanics are risk factors for knee injury in runners and athletes ([13]).
The explanation given by the authors for the increased values in frontal plane movement, during running with one arm restrained but not the other arm swing conditions, is that the freely swinging arm allowed for similar trunk motion as the typical arm swing. However, total arm swing may not have been adequate to reduce the effects of angular momentum and thus a change in frontal plane movement occurred.
Larger foot strike angles and vertical center of mass excursions are associated with higher lower extremity loads and present a higher risk for injury ([14]). Agresta and colleagues ([9]) found that foot strike angle and vertical COM displacement were

significantly smaller during the unilateral arm swing condition compared to typical arm swing running but they also state that runners included in the study had an overall lower foot strike angle than what has been reported in the literature and this discrepancy could be explained by the fact that there was no restriction on the type of footwear or history of gait retraining in the selection criteria.

Authors also found that as arm swing decreased (i.e. one arm and then no arms) runners took smaller, faster steps. Stride time, length, and frequency were all significantly altered for each arm swing condition with the smallest step length and highest step frequency occurring when bilateral arm swing was restricted.

Participants in the study ran at a constant speed, however, the change in spatiotemporal measures suggests an attempt to slow down while running with restrained arm movement.

Brooks and colleagues ([10]), assuming that natural running arm swing minimizes rotation of the runner's body about its vertical axis when running in a straight line, state that compensatory upper body motion may have effectively replaced arm swing during the restrained arm sprint trials, thereby constraining the body's vertical rotations to levels approximating the normal arm condition.

In the restricted arm condition, the qualitative observations indicated participants had substantially greater torso rotations.

Miller and colleagues ([11]) found that suppressing arm swing bilaterally the peak vertical GRF decreased, and the peak hip and knee flexion angles increased. In the frontal plane the peak lateral GRF and the hip and knee adduction angles were also altered and the duration of stance increased. Regarding the control of the lower extremity, center of mass trajectory, and external force generation, the results indicate that arm swing suppression alters the mechanism of the center of mass support and the control of the frontal plane motion the medial-lateral GRF and hip and knee joint adduction/abduction during stance. The increase in stance duration when arm swing was suppressed may be reconciled as an adjustment made by the subjects to maintain the vertical impulse when the peak vertical GRF decreased with arm swing suppression.

Otsuka and colleagues ([12]) tried to clarify the changes in sprint speed and kinematic parameters in the constraint condition of the scapulothoracic joints finding that the scapular behavior in the backward-swinging arm coordinates with humerothoracic extension and contralateral hip extension, thereby enhancing sprint speed.
Compared to the constraint of the arm-swing motion, the limited scapular motion may have a stronger effect on the decrease of sprint speed.
Humerothoracic extension of the backward-swinging arm was smaller in the constraint condition compared with that in the free condition. These findings suggest that compared with the humerothoracic flexion motion, extension is more sensitive to constraint of the scapulothoracic joint.
The 3D scapular behavior in first accelerated running may play a role in increasing humerothoracic extension of the backward arm and hip extension of the stance leg, thereby contributing to coordinated whole-body balance for great sprint acceleration. In addition, step length to first step was longer in the free condition than that in the constraint condition. This suggests that scapular behavior affects the beginning of motion in sprint running immediately before the first step affecting the ability of the sprinter to enhance sprint speed.

5.2 Practical implication

Unilateral arm swing restriction during running has a significant negative effect on contralateral frontal plane hip and knee mechanics. Coaches and sport clinicians should consider using sport equipment or various ball-carry techniques and likely include return to running programs with upper limb swing restrictions in return to sport phases, in order to replicate the sport specific movement of the athlete.
As arm swing decreased runners took smaller, faster steps. Stride time, length and frequency were all significantly altered with the smallest step length and highest step frequency occurring when bilateral arm swing was restricted ([9]). This suggests that

arm swing restriction can be used to manage spatiotemporal variables in running retraining programs as an alternative to the ordinary methods widely described in the literature.

Arm swing restriction seems to reduce running speed: Agresta et al. ([9]) and Brooks et al. ([10]) find out that restricting arm swing results in a lower running speed. Results doesn't seem to be remarkably small. Therefore, the differences observed could be critical to finishing place in competitive sprints. Sport clinicians should consider arm swing motion in running retraining especially when talking about high-level athletes. Arm swing suppression led to a reduction in peak vertical ground reaction force ([11]). Higher vertical impact variables are associated to patellofemoral pain and plantar fasciitis ([13]). This suggest that practitioners can use arm swing motion in order to address impact loading in their treatment of injured runners.

When the arm-swing motion was restricted by constraining scapular motion ([12]), it clearly limited the humerothoracic extension of the backward-swinging arm. As a result, this scapular constraint affected the stance-leg motion and whole-body position during the first step, thereby reducing the sprint speed. These findings may be applied to the followings: for athletes with low scapular flexibility, improving it by performing scapular flexibility exercises (e.g. stretching, accessory or physiological mobilization) is important as it may be related to improvement in the generated sprint speed. Also, for female athletes, the effects of compressing both scapulae by a sports bra would affect to sprinting performance in first accelerated running.

5.3 Limitation

There are several limitations in the studies included starting from the small number of participants, which might underpower our analysis of some variables. As reported by Agresta and colleagues ([9]) trunk motion contributes to lower extremity dynamics but it was not possible to determine how much this affected the results.

Brooks and colleagues ([10]) also state that additional habituation could potentially reduce the between-condition performance effects in particular for the track field athletes who had a more difficult motor task to acquire due to the modified starting position.

6. CONCLUSION

The results of this review allow to conclude for certain that running with arm restriction is different than running with typical arm swing.
This review sets the stage for new studies: it is still too early to be able to draw firm conclusions on how the upper limb can influence running parameters. However, these first results are interesting and can be an important starting point for future studies that should consider larger populations and more homogeneous interventions with common outcomes in order to generalize the data.
Therefore, the role of the upper limb in running is not yet clear and further studies need to be done in order to improve understanding related to arm mechanics during running.

APPENDIX

Appendix A

JBI Critical Appraisal Checklist for Analytical Cross-Sectional Studies

	Yes	No	Unclear	Not applicable
1. Were the criteria for inclusion in the sample clearly defined?	☐	☐	☐	☐
2. Were the study subjects and the setting described in detail?	☐	☐	☐	☐
3. Was the exposure measured in a valid and reliable way?	☐	☐	☐	☐
4. Were objective, standard criteria used for measurement of the condition?	☐	☐	☐	☐
5. Were confounding factors identified?	☐	☐	☐	☐
6. Were strategies to deal with confounding factors stated?	☐	☐	☐	☐
7. Were the outcomes measured in a valid and reliable way?	☐	☐	☐	☐
8. Was appropriate statistical analysis used?	☐	☐	☐	☐

Overall appraisal: Include ☐ Exclude ☐ Seek further info ☐

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