Validity and Reliability of 2-Dimensional Video-Based Assessment to Analyze Foot Strike Pattern and Step Rate During Running: A Systematic Review

Fábio Carlos Lucas de Oliveira, PT, PhD,[†‡] Anny Fredette, PT,[†‡§] Sherezada Ochoa Echeverría, MSc,[†] Charles Sebiyo Batcho, PT, PhD,[†||] and Jean-Sébastien Roy, PT, PhD*[†||]

Context: Two-dimensional (2D) video-based analysis is often used by clinicians to examine the foot strike pattern (FSP) and step rate in runners. Reliability and validity of 2D video-based analysis have been questioned.

Objective: To synthesize the psychometric properties of 2D video-based analysis for assessing runners' FSP and step rate while running.

Data Sources: Medline/PubMed, Science Direct, Embase, EBSCOHost/CINAHL, and Scielo were searched from their inception to August 2018.

Study Selection: Studies were included if (1) they were published in English, French, Portuguese or Spanish; (2) they reported at least 1 psychometric property (validity and/or reliability) of 2D video-based analysis to assess running kinematics; and (3) they assessed FSP or step rate during running.

Study Design: Systematic review.

Level of Evidence: Level 2.

Data Extraction: Studies were screened for methodological (MacDermid checklist) and psychometric quality (COSMIN checklist) by 2 independent raters.

Results: Eight studies, with a total of 702 participants, were included. Seven studies evaluated the reliability of 2D video to assess FSP and found very good to excellent reliability ($0.41 \le \kappa \le 1.00$). Two studies reported excellent reliability for the calculation of step rate ($0.75 \le$ intraclass correlation coefficient [ICC] ≤ 1.00). One study demonstrated excellent concurrent validity between 2D and 3D (gold standard) motion capture systems to determine FSP (Gwet agreement coefficient [AC] > 0.90; ICC > 0.90), and another study found excellent concurrent validity between 2D video and another device to calculate step rate ($0.84 \le$ ICC ≤ 0.95).

Conclusion: Strong evidence suggests that 2D video-based analysis is a reliable method for assessing FSP and quantifying step rate, regardless of the experience of the assessor. Limited evidence exists on the validity of 2D video-based analysis in determining FSP and calculating step rate during running.

Keywords: psychometric properties; running-related injuries; prevention; clinical observation

From [†]Centre for Interdisciplinary Research in Rehabilitation and Social Integration, CIUSSS-CN, Quebec City, Quebec, Canada, [‡]Faculty of Medicine, Université Laval, Quebec City, Quebec, Canada, [§]Department of Physiotherapy, Valcartier Garrison, Canadian Forces Health Services Group Headquarters, Quebec City, Quebec, Canada, and [||]Department of Rehabilitation, Faculty of Medicine, Université Laval, Quebec City, Quebec, Canada

*Address correspondence to Jean-Sébastien Roy, PT, PhD, Centre for Interdisciplinary Research in Rehabilitation and Social Integration, 525 Boulevard Wilfrid-Hamel, Quebec City, Quebec, G1M 2S8, Canada (email: jean-sebastien.roy@rea.ulaval.ca).

The following authors declared potential conflicts of interest: F.C.L.D.O. receives a doctoral scholarship from the Brazilian Government through the Science Without Borders program in association with the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior–CAPES. J.S.R. is supported by salary awards from the Fonds de Recherche Québec-Santé and the Canadian Institutes of Health Research.

DOI: 10.1177/1941738119844795

Running is an increasingly popular activity because of its practicality and accessibility but especially because of the health and fitness benefits provided.[3] The high incidence of musculoskeletal injuries is a worrisome factor among runners. In fact, the overall incidence of running-related injuries (RRIs) across all types of runners ranges from 11% to 85% on a yearly basis.[3,27,38] The most common injuries are patellofemoral pain, iliotibial band syndrome, and stress fractures to the tibia and metatarsals.[36] Several risk factors contributing to RRIs are well documented. First, there are intrinsic or personal factors such as age, sex, physical fitness, previous injury, running experience, muscular weakness, or inadequate lower extremity dynamic control.[3,9,25,27,28] Then there are extrinsic factors such as the running characteristics (distance, duration, frequency, intensity), running surface, and type of running shoes.[3] Although causative factors of RRIs are multifactorial, most agree that running biomechanics play an important role in the occurrence of overuse injuries.[36] More specifically, the foot strike pattern (FSP), which is usually defined in 3 categories (rearfoot, midfoot, or forefoot strike), appears to be related to the risk of developing lower limb RRIs.[1,14,36] The heel strike pattern has been associated with a higher vertical loading rate, therefore increasing the risk of overuse injury. Similarly, a lower running step rate is associated with a higher initial impact force, contributing to overuse injury.[36,40] Therefore, the assessment of lower limb kinematics is an inherent part of the clinical evaluation for RRIs.

Although 3-dimensional (3D) kinematics motion-capture systems are considered the gold standard for evaluating the lower limb kinematics,[17,21,34] 2D video-based analysis is preferred by clinicians because of its feasibility and effectiveness. The typical clinical setup used to assess lower limb kinematics using a 2D video system simply includes a treadmill and a high-definition video camera, which are feasible for practical use in clinics.

Several studies have reported different indices of validity and reliability for 2D video-based analysis to assess running kinematics. Maykut et al[21] investigated the reliability and concurrent validity of 2D video-based analysis against a 3D video system for evaluating the frontal plane kinematics during treadmill running. They reported that 2D video systems are a valid and reliable tool.[21] Dingenen et al[8] demonstrated a significant relationship between 2D measured frontal plane joint angles (contralateral pelvic drop and hip adduction) and 3D measured kinematic profiles besides excellent intra- and interrater reliability for determining the 2D angles (intraclass correlation coefficient [ICC] = 0.90-0.99). Hence, their findings support the use of 2D video-based analysis to evaluate these kinematic variables during running.[8] Damsted et al[5] demonstrated that the 2D motion analysis is "sufficiently" reliable to quantify the knee and hip angles during foot strike with treadmill running. The aim of this systematic review is to analyze the current evidence regarding the psychometric properties of the 2D video-based assessment to determine the runners' FSP and step rate while running.

METHODS

Literature Search and Study Identification

Bibliographical searches were conducted in 5 databases (Medline/PubMed, Science Direct, Embase, EBSCOHost/CINAHL, and Scielo) to find articles evaluating the psychometric properties of the 2D video systems as an assessment tool to analyze lower limb kinematics during running. All databases were searched from their inception to August 2018, exploring 4 concepts (psychometric properties, assessment tools, kinematics, activity/athletes). The following search strategies were used: (validity OR reliability) AND (video OR videotap* OR "video-based" OR "2D video" OR "clinical observation" OR "smartphone" OR iphone) AND ("foot strike" OR "step rate" OR cadence OR "heel strike" OR "stride" OR "running form" OR "lower limbs kinematics" OR "foot biomechanics") AND (running OR runners). This strategy was tailored for each database using the appropriate truncation and medical subject heading. Bibliographical references of the retrieved studies were also searched to identify additional relevant publications that were not drawn through strategical searches.

The process used to select the articles for this systematic review follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Figure 1). First, duplicated articles were removed. Thereafter, 3 raters independently screened the publications' titles and abstracts to determine the eligible studies for detailed review (full text). The raters were blinded to each other's evaluations. To be selected for full-text review, the article had to (1) be published in English, French, Portuguese, or Spanish; (2) report at least 1 psychometric property (validity and/or reliability) of the 2D video-based analysis to assess running kinematics; and (3) examine FSP or step rate during running. Two raters independently scrutinized the full text of all potentially eligible studies to confirm their inclusion. Eligibility was always granted by consensus; however, the evaluation of the third reviewer was used to make the final decision when no consensus was reached with the evaluations of the first 2 raters.

Quality Assessment of the Studies

Methodological Quality (Critical Appraisal)

The methodological quality of the included studies was assessed using a structured quality appraisal tool developed by MacDermid.[20] Previous literature using this tool to assess psychometric properties reported excellent preconsensus interrater reliability (ICC = 0.89-0.91).[32,33] The scale is composed of 12 items rated from 0 to 2, pertaining to the study question and design, measurement methods, analyses, and recommendations.[20]

Two raters independently evaluated each article using the MacDermid checklist (Appendix Table A1, available in the online version of this article). A Cohen kappa calculation was used to determine the preconsensus interrater agreement on each item from the checklist, whereas ICC was calculated for the preconsensus final scores. Thereafter, a comparison of

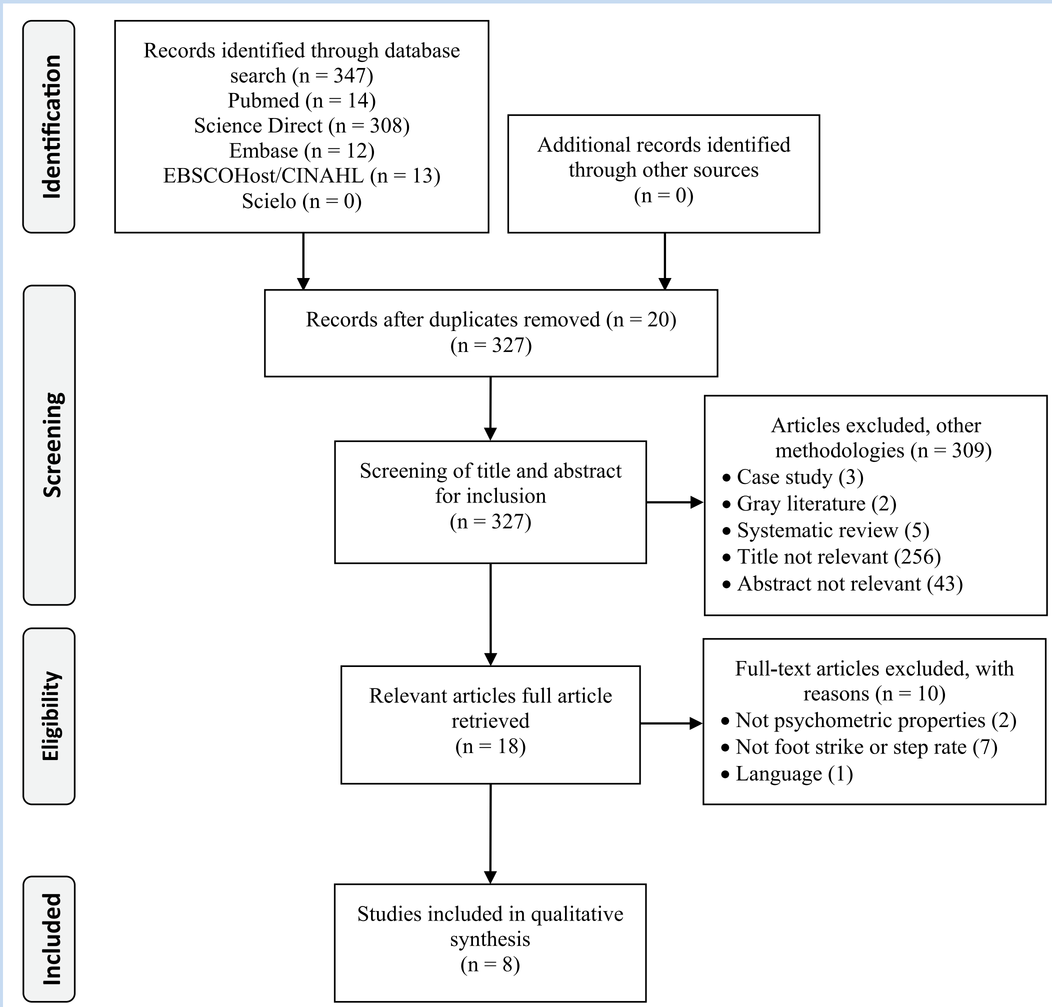

Figure 1. Flowchart describing the article selection process according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.

ratings was performed in a meeting between the raters to reach a consensus for scoring. When a consensus was not reached, a third rater was available to contribute to the final decision.

As summary scores for the MacDermid checklist are not available, the following evaluation index, reported by de Oliveira et al,[7] was used to determine the scores for qualitative categories: "high quality" (HQ) ≥80.0%, "good quality" (GQ) between 70.0% and 79.9%, "moderate quality" for scores between 50.0% and 69.9%, and "low quality" representing scores <50.0%.

Psychometric Properties (Critical Appraisal)

Studies were critically appraised using the recommendations of the COnsensus-based Standards for the selection of health Measurement INstruments (COSMIN) checklist (Appendix Table A2, available online).[23] The COSMIN checklist is composed of 10 boxes (A to J), each containing between 5 and 18 items/questions, addressing psychometric properties such as internal consistency, reliability, measurement error, content validity, structural validity, hypotheses testing, cross-cultural validity, criterion validity, responsiveness, and interpretability. This tool uses a 4-point rating scale to assess each item (excellent, good, fair, and poor), to identify whether specific measurement properties reach the standard for adequate methodological quality.[37] As the psychometric properties assessed in this systematic review include reliability measures (inter- and intrareliability), measurement error (absolute measures), and criterion validity,[24,31] only the boxes for these properties were filled. Again, 2 raters evaluated each article independently (Appendix Table A2, available online). Thereafter, the assessors met to openly discuss the specific domains to reach a consensus for each article. A preconsensus interrater agreement was also calculated using Cohen kappa and ICC values for each item and for the total scores, respectively.

Data Extraction

Two raters extracted data from the studies using a structured data collection form[20] adapted for this systematic review

(Appendix Table A3, available online). A third assessor compiled and completed the extraction for missing data.

Validity and reliability of 2D video analysis were the 2 psychometric properties evaluated through this systematic review. They were investigated in relation to the 2 outcomes of interest: FSP and step rate during running. Parameters extracted from the studies were authors, publication year, sample characteristics, objectives/purposes, outcomes, psychometric properties examined, type of 2D video setup, and comparison with gold standard, as well as results reported as Cohen kappa, ICC, SEM, or limit of agreement in percentage.

Data Analysis

The level of evidence for the psychometric properties of the 2D video system to assess the main outcomes was determined based on the recommendations of the Cochrane Group Collaboration,[39] which defines the strength of the evidence as strong, moderate, conflicting, limited, or very limited (Appendix Table A4, available online).[2,7,39] The strength of recommendations was determined by the following domains: *imprecision* (number of studies/participants), *risk of bias* (methodological quality), *indirectness* (methodological and outcome similarities), and *inconsistency* (direction of results).[7]

RESULTS

With the first electronic search, 347 articles were retrieved. Duplicates were subsequently removed (20 excluded), 327 title/abstracts were screened (309 excluded) and 18 articles were preselected for full-text analysis. However, 1 article was written in German, 2 articles did not examine the psychometric properties of interest (reliability and validity), and 7 studies did not investigate the FSP or step rate. For these reasons, they were excluded. Therefore, 8 studies were included in the systematic review. No additional articles were identified for inclusion during handsearching of the selected studies' references.

Characteristics of the Studies

Inter- or intrarater reliability of FSP was the most investigated psychometric property[4,6,10,12,18,19,29] as 87.5% of the articles (7/8) reported on this property (Appendix Table A3, available online). A total of 702 participants were investigated with sample sizes ranging from 13 participants[18] to 514 participants.[6]

Methodological Quality

The summary scores of the methodological quality ranged from 70% to 95.5%. On average, the studies presented high methodological quality with a mean score of 81.6% ± 7.5% on the MacDermid scale (Appendix Table A1, available online). Five studies (62.5%) were classified as "high quality" and 3 (37.5%) as "good quality." No study was classified as "moderate" or "low quality."

Most of the studies (5/8, 62.5%)[4,12,13,19,29] did not use an appropriate sample size, whereas 2 studies[10,18] (25.0%) failed in reporting the sample size calculation or a rationale for their sample size. Only 2 studies[10,18] reported adequately the inclusion and exclusion criteria used. One study[6] did not use adequate statistical analysis and 6 studies[4,6,12,13,19,29] omitted information on inclusion and exclusion criteria.

Despite a moderate preconsensus interrater agreement (κ = 0.509-0.679) between the individual items of each rater evaluation using the MacDermid checklist, a good preconsensus interrater reliability for the total score (ICC = 0.79, 95% CI = 0.27-0.96) was observed.

Psychometric Properties

The studies that reported the psychometric properties of the 2D video system to determine FSP and step rate ranged from good to excellent according to the COSMIN assessment checklist (Appendix Table A2, available online). Three studies[4,10,29] specifically investigated the psychometric properties of the 2D video system to determine FSP and step rate, whereas 5 studies[6,12,13,18,19] mainly focused on other aspects of the lower limb kinematics during running but were included in the study because they reported the reliability of the 2D video system to determine FSP. All included studies addressed either the inter- or intrarater reliability of the 2D video for at least 1 of the outcomes of interest, and most of them reported a measurement error for the 2 outcomes of interest. Two articles investigated the validity of the 2D video: A single study[10] evaluated the concurrent validity of the 2D video system in determining the FSP compared with 3D video as a gold standard; another study[13] used the Myotest and Optojump to evaluate the concurrent validity of the 2D video analysis in quantifying the step rate. Only 1 study[29] clearly reported how the missing data were handled, 5 articles (62.5%)[6,10,12,18,19] failed to calculate the weighted kappa, and 5 articles[4,6,12,18,19] failed to describe the weighting scheme for ordinary scores. Lastly, 3 studies[13,18,19] did not report whether procedures were administered independently.

Cohen kappa revealed very good preconsensus interrater agreement in the scores evaluated with the COSMIN checklist (κ = 0.855-1.000) (Appendix Table A2, available online). The preconsensus interrater reliability was good for the rating related to measurement errors (COSMIN checklist, Box C) (ICC = 0.879, 95% CI = 0.514-0.975) and excellent for reliability measures (Box B) and criterion validity (Box H) (ICC = 0.958, 95% CI = 0.808-0.992 and ICC = 1.000, respectively).

To facilitate understanding, the results of the gathered studies are reported according to the outcomes examined and the psychometric properties (Appendix Table A3, available online). The level of evidence found for the psychometric properties examined is available in Appendix Table A5 (available online).

Foot Strike Patterns

Inter- and Intrarater Reliability

There is strong evidence that the 2D video system is highly reliable (intra- and interrater reliability) in determining FSP during running on a treadmill. Six out of 7 studies[6,10,12,18,19,29] (4 HQ, 2 GQ) investigated the intra- and interrater reliability and found excellent or very good coefficients for these psychometric properties (Gwet's agreement coefficient [AC] > 0.92 or κ > 0.80) (Appendix Table A3, available online). A single GQ study[4] found good (κ = 0.63-0.69) and moderate coefficients (κ = 0.41-0.53) for inter- and intrareliability, respectively, for the 2D video system to assess FSP during running.

Validity

There is limited evidence that 2D video is a valid method of assessing FSP during treadmill running. A single HQ study[10] found excellent agreement coefficients (>0.90) between 2D video analysis and the 3D motion analysis system to determine FSP in patients with patellofemoral pain.[10]

Step Rate

Inter- and Intrarater Reliability

There is strong evidence that a 2D video system is a highly reliable tool to assess step rate during running. Two HQ studies,[10,13] found excellent interrater reliability coefficients (ICC > 0.90) using a 2D video system to calculate the step rate during treadmill running.

Evidence for the intrarater reliability of the 2D video for calculating the step rate is limited. A single HQ study[10] found excellent intra-rater coefficients for both novice and experienced assessors (ICC = 0.984 and 0.998, respectively) during evaluation of the step rate in patients with patellofemoral syndrome using a 2D video system.

Validity

Limited evidence exists on the concurrent and overall validity of the 2D video for calculating step rate in recreational runners. A single HQ study[13] found an excellent coefficient (ICC = 0.901) for measuring running step rate when compared with the Myotest accelerometric system and Optojump Next modular system to evaluate the strides.

DISCUSSION

The purpose of this systematic review was to synthesize the current evidence concerning validity and reliability of the 2D video-based assessment in determining the FSP and calculating the step rate during running. Our main finding was the strong evidence suggesting that 2D video analysis is a highly reliable tool for determining FSP and calculating the step rate during running. In contrast, evidence that the 2D video analysis is valid for the same outcomes is still limited and more studies are needed.

Despite the existence of several methods for evaluating the FSP such as force plates, pressure plates, accelerometers, and so on, 2D video analysis emerges as the cheapest and easiest to install, providing convenience and cost-effectiveness for clinicians.[22,34] The FSP during treadmill running can be quantified in a reliable manner by clinical observation. Altman and Davis[1] validated the real-time visual assessment of FSP against a gold standard (3D kinematics). However, this real-time evaluation does not allow as meticulous analysis as using the video recording equipment. Reevaluation or interrater comparison can be easily performed when video recording is available. Therefore, clinicians often review the gait or running videos using slow playback or frame-by-frame to evaluate gait or running.[29]

In clinical practice, the FSP assessments can be useful for evaluating risk factors of lower limbs RRIs. Therefore, it is crucial that this evaluation be reliable. The reliability of the 2D video analysis in evaluating and classifying the FSP can be examined according to the type of strike (rearfoot, midfoot, forefoot strike). de Almeida et al[6] demonstrated that most recreational runners were rearfoot (95.1%), while 4.1% was midfoot, and 0.8% forefoot strikers during running. Runners with rearfoot strikes are believed to be more susceptible to RRIs[16] due to increased vertical loading rates compared with midfoot and forefoot.[35] Although there is some divergence on the influence of the FSP on RRIs, clinicians are recommended to assess the FSP as part of their clinical interventions. Sometimes, runners are advised to change their FSP during the rehabilitation process.[4]

Three parameters have been suggested as potential factors that could influence the validity and the reliability of 2D video analysis of FSP and step rate; namely, the clinical experience of the assessor, settings for 2D video recordings, and categorization of FSP. The next 3 sections will, therefore, discuss these 3 factors.

Clinical Experience of the Assessor

Esculier et al[10] demonstrated that the experience of the assessor does not affect the reliability of a 2D video analysis in assessing the FSP or calculating the step rate. The authors analyzed the performance of novice and experienced clinicians in examining both the FSP and the step rate of runners with patellofemoral pain during treadmill running. No significant differences between novice and experienced assessors were observed for intra- and interrater reliability and concurrent validity analysis.

Settings for 2D Video Recordings

The video assessments can be hampered by the setup. For instance, excessive light or pixelation in cameras may influence the reliability of a 2D video analysis, having a direct impact on the image quality.[4] A previous study[6] has argued that video analysis for identifying the stride events, especially the initial foot contact, is harder when using a lower frequency camera, which may increase the possibility of misclassification of the FSP.[11,29]

Hasegawa et al[15] used a 120-Hz video camera to determine the FSP. More recently, Pipkin et al[29] demonstrated that a 2D video camera at 120 Hz is reliable for assessing the initial contact, midstance, and midflight during gait. The authors found that adequate intrarater reliability was observed in both healthy and injured runners. Esculier et al[10] used a simple 30-Hz high-speed video camera to record images. Their results demonstrated that an excellent index of reliability of the 2D video analysis on FSP and step rate can be achieved with a camera of 30 Hz. Therefore, the 2D video assessments do not require very expensive equipment since a lower frame rate camera did not affect the reliability of the 2D video assessments.

Categorization of FSP

The type of scale used to determine FSP was one of the main differences among the included studies. Two of them used a 3-point scale, 1 used a 4-point scale, and 4 used 5-point scale categories.

According to Munro et al,[26] FSP categorized in a 5-point scale may replicate more realistically the dynamics of the human movement in comparison with 3-point scales. Damsted et al[4] categorized the FSP in 5 categories (heel, heel/midfoot, midfoot, midfoot/forefoot, and forefoot) and argued that 5-point scales may allow more detailed comparison of breaking patterns among the scales, which may increase the accuracy in detecting specific injuries related to the FSP. Studies using 5-point scales often argue that 3-point scales are not enough to evaluate the direct correlation between the risk of RRIs due to velocity, direction, and timing of a foot strike.[4] Notwithstanding, while some studies have ascertained that 5-point scales may provide an important effect on the identification of the FSP, and therefore enhance clinical relevance, other studies have found similar results using 3- or 4-point scales, in terms of reliability. Pipkin et al[29] found excellent reliability (κ = 0.85-0.86) of a running gait analysis using 4 categories of FSP (heel, rearfoot, midfoot, forefoot strike). Their results showed good reliability in gait-event detection and very low error (<0.01 s at 120 Hz) for detecting initial contact and midstance.[29] Hasegawa et al[15] and, more recently, Esculier et al[10] supported the use of 3-point scales for determining the FSP as a better option to optimize the reliability of the 2D video analysis. Nonetheless, Esculier et al[10] showed that the reliability of the 2D video setup is not compromised by the number of categories in which the FSP is classified. In this context, our results confirmed that the number of categories or scales used for examining the FSP seems not to affect the reliability of the 2D video analysis. Results from Esculier et al[10] also support the use of the 2D video analysis as a valid method for evaluating both the FSP and the step rate, since good to excellent concurrent validity were observed using 2 (rearfoot, non–rearfoot strike) or 3 categories (rearfoot, midfoot, forefoot strike).

Limitations

Despite the methodological rigor of our systematic review, we recognize several limitations of this study. First, 62.5% of the studies included in this systematic review[6,12,13,18,19] reported the psychometric properties of the 2D video analysis as a secondary objective. Therefore, relevant discussions on the psychometric properties of the 2D video analysis were not provided. Second, few studies have investigated the validity of the 2D video-based analysis for the outcomes of interest. Third, 75% or more of the studies failed to report information on inclusion and exclusion criteria or presented an inadequate sample size, which may have influenced our critical appraisal. Finally, it is important to highlight that although kinetics and kinematics evaluated on a treadmill are comparable with overground running, they are not equivalent. In fact, for treadmill-based evaluations to be reliable, the treadmill surface needs to be sufficiently stiff and the belt speed adequately regulated.[30] These parameters may influence the clinicians' evaluation of FSP and step rate.

Clinical Recommendations

Based on the evidence concerning reliability, we recommend the use of the 2D video analysis to determine the FSP and to calculate the step rate during running. Among the reasons that justify our decision of recommending the 2D video for analysis of FSP and step rate, we highlight the excellent results observed for both outcomes. In addition, the fact that clinicians do not need to be experienced in using 2D video systems corroborates this recommendation.

Although the validity of the 2D video systems has not been confirmed yet, the few studies that have examined it have presented excellent results. Therefore, clinicians and researchers have good reasons to be confident about using the 2D video analysis to guide their gait analysis and interventions.

To ensure high quality of the video recordings, a critical evaluation of the physical setup prior to data collection (calibration of angles, distance between device and runner, illumination, etc) is recommended.[5] Furthermore, a standardized assessment procedure for analyzing running gait using a 2D video system may increase the quality of recordings, increase reliability, and ensure clinical effectiveness.[36]

CONCLUSION

Strong evidence confirms that 2D video-based assessment is reliable in determining FSP and calculating step rate during running. However, limited evidence indicates that the 2D video system is valid in determining FSP and step rate during running.

REFERENCES

1. Altman AR, Davis IS. A kinematic method for footstrike pattern detection in barefoot and shod runners. *Gait Posture*. 2012;35:298-300.
2. Barton CJ, Lack S, Malliaras P, Morrissey D. Gluteal muscle activity and patellofemoral pain syndrome: a systematic review. *Br J Sports Med*. 2013;47:207-214.
3. Buist I, Bredeweg SW, Bessem B, van Mechelen W, Lemmink KA, Diercks RL. Incidence and risk factors of running-related injuries during preparation for a 4-mile recreational running event. *Br J Sports Med*. 2010;44:598-604.
4. Damsted C, Larsen LH, Nielsen RO. Reliability of video-based identification of footstrike pattern and video time frame at initial contact in recreational runners. *Gait Posture*. 2015;42:32-35.
5. Damsted C, Nielsen RO, Larsen LH. Reliability of video-based quantification of the knee- and hip angle at foot strike during running. *Int J SPorts Phys Ther*. 2015;10:147-154.
6. de Almeida MO, Saragiotto BT, Yamato TP, Lopes AD. Is the rearfoot pattern the most frequently foot strike pattern among recreational shod distance runners? *Phys Ther Sport*. 2015;16:29-33.
7. de Oliveira FCL, Bouyer LJ, Ager AL, Roy JS. Electromyographic analysis of rotator cuff muscles in patients with rotator cuff tendinopathy: a systematic review. *J Electromyogr Kinesiol*. 2017;35:100-114.
8. Dingenen B, Staes FF, Santermans L, et al. Are two-dimensional measured frontal plane angles related to three-dimensional measured kinematic profiles during running? *Phys Ther Sport*. 2018;29:84-92.
9. Dudley RI, Pamukoff DN, Lynn SK, Kersey RD, Noffal GJ. A prospective comparison of lower extremity kinematics and kinetics between injured and non-injured collegiate cross country runners. *Hum Mov Sci*. 2017;52:197-202.

10. Esculier JF, Silvini T, Bouyer LJ, Roy JS. Video-based assessment of foot strike pattern and step rate is valid and reliable in runners with patellofemoral pain. *Phys Ther Sport*. 2018;29:108-112.
11. Fellin RE, Manal K, Davis IS. Comparison of lower extremity kinematic curves during overground and treadmill running. *J Appl Biomech*. 2010;26:407-414.
12. García-Pinillos F, Molina-Molina A, Párraga-Montilla JA, Latorre-Román PA. Kinematic alterations after two high-intensity intermittent training protocols in endurance runners [published online November 16, 2016]. *J Sport and Health Sci*. doi:10.1016/j.jshs.2016.11.003
13. Gindre C, Lussiana T, Hebert-Losier K, Morin JB. Reliability and validity of the Myotest® for measuring running stride kinematics. *J Sports Sci*. 2016;34:664-670.
14. Hall JP, Barton C, Jones PR, Morrissey D. The biomechanical differences between barefoot and shod distance running: a systematic review and preliminary meta-analysis. *Sports Med*. 2013;43:1335-1353.
15. Hasegawa H, Yamauchi T, Kraemer WJ. Foot strike patterns of runners at the 15-km point during an elite-level half marathon. *J Strength Cond Res*. 2007;21:888-893.
16. Hreljac A. Etiology, prevention, and early intervention of overuse injuries in runners: a biomechanical perspective. *Phys Med Rehabil Clin N Am*. 2005;16:651-667.
17. Knorz S, Kluge F, Gelse K, et al. Three-dimensional biomechanical analysis of rearfoot and forefoot running. *Orthop J Sports Med*. 2017;5:2325967117719065.
18. Latorre-Román PA, García-Pinillos F, Soto-Hermoso VM, Muñoz-Jiménez M. Effects of 12 weeks of barefoot running on foot strike patterns, inversion-eversion and foot rotation in long-distance runners [published online January 11, 2016]. *J Sport Health Sci*. doi:10.1016/j.jshs.2016.01.004
19. Latorre-Román PÁ, García Pinillos F, Bujalance-Moreno P, Soto-Hermoso VM. Acute effects of high-intensity intermittent training on kinematics and foot strike patterns in endurance runners. *J Sports Sci*. 2017;35:1247-1254.
20. MacDermid JC. Critical appraisal of study design for psychometric articles evaluation form and interpretation guide. In: Law M, ed. *Evidence-Based Rehabilitation: A Guide to Practice*. Thorofare, NJ: Slack; 2008:387-392.
21. Maykut JN, Taylor-Haas JA, Paterno MV, DiCesare CA, Ford KR. Concurrent validity and reliability of 2D kinematic analysis of frontal plane motion during running. *Int J Sports Phys Ther*. 2015;10:136-146.
22. Milner CE, Paquette MR. A kinematic method to detect foot contact during running for all foot strike patterns. *J Biomech*. 2015;48:3502-3505.
23. Mokkink LB, Terwee CB, Patrick DL, et al. The COSMIN checklist for assessing the methodological quality of studies on measurement properties of health status measurement instruments: an international Delphi study. *Qual Life Res*. 2010;19:539-549.
24. Mokkink LB, Terwee CB, Patrick DL, et al. The COSMIN study reached international consensus on taxonomy, terminology, and definitions of measurement properties for health-related patient-reported outcomes. *J Clin Epidemiol*. 2010;63:737-745.
25. Molloy JM. Factors influencing running-related musculoskeletal injury risk among U.S. military recruits. *Mil Med*. 2016;181:512-523.
26. Munro CF, Miller DI, Fuglevand AJ. Ground reaction forces in running: a reexamination. *J Biomech*. 1987;20:147-155.
27. Nielsen RO, Buist I, Sorensen H, Lind M, Rasmussen S. Training errors and running related injuries: a systematic review. *Int J Sports Phys Ther*. 2012;7:58-75.
28. Nielsen RO, Nohr EA, Rasmussen S, Sorensen H. Classifying running-related injuries based upon etiology, with emphasis on volume and pace. *Int J Sports Phys Ther*. 2013;8:172-179.
29. Pipkin A, Kotecki K, Hetzel S, Heiderscheit B. Reliability of a qualitative video analysis for running. *J Orthop Sports Phys Ther*. 2016;46:556-561.
30. Riley PO, Dicharry J, Franz J, Della Croce U, Wilder RP, Kerrigan DC. A kinematics and kinetic comparison of overground and treadmill running. *Med Sci Sports Exerc*. 2008;40:1093-1100.
31. Roy JS, Desmeules F, MacDermid JC. Psychometric properties of presenteeism scales for musculoskeletal disorders: a systematic review. *J Rehabil Med*. 2011;43:23-31.
32. Roy JS, MacDermid JC, Woodhouse LJ. Measuring shoulder function: a systematic review of four questionnaires. *Arthritis Rheum*. 2009;61:623-632.
33. Roy JS, MacDermid JC, Woodhouse LJ. A systematic review of the psychometric properties of the Constant-Murley score. *J Shoulder Elbow Surg*. 2010;19:157-164.
34. Santuz A, Ekizos A, Arampatzis A. A pressure plate-based method for the automatic assessment of foot strike patterns during running. *Ann Biomed Eng*. 2016;44:1646-1655.
35. Shih Y, Lin KL, Shiang TY. Is the foot striking pattern more important than barefoot or shod conditions in running? *Gait Posture*. 2013;38:490-494.
36. Souza RB. An evidence-based videotaped running biomechanics analysis. *Phys Med Rehabil Clin N Am*. 2016;27:217-236.
37. Terwee CB, Mokkink LB, Knol DL, Ostelo RW, Bouter LM, de Vet HC. Rating the methodological quality in systematic reviews of studies on measurement properties: a scoring system for the COSMIN checklist. *Qual Life Res*. 2012;21:651-657.
38. van Gent RN, Siem D, van Middelkoop M, van Os AG, Bierma-Zeinstra SM, Koes BW. Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review. *Br J Sports Med*. 2007;41:469-480.
39. van Tulder M, Furlan A, Bombardier C, Bouter L, Editorial Board of the Cochrane Collaboration Back Review Group. Updated method guidelines for systematic reviews in the Cochrane Collaboration Back Review Group. *Spine (Phila Pa 1976)*. 2003;28:1290-1299.
40. Willy RW, Willson JD, Clowers K, Baggaley M, Murray N. The effects of body-borne loads and cadence manipulation on patellofemoral and tibiofemoral joint kinetics during running. *J Biomech*. 2016;49:4028-4033.