Title: The Sprint Mechanics Assessment Score (S-MAS): a qualitative screening tool for the in-field assessment of sprint running mechanics.

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Social Media Statement: New Article: The Sprint Mechanics Assessment Score. A reliable tool for the in-field assessment of sprint running mechanics @chrisbramah @TomDosSantos91 @EatSleepTrain_ @sammyrhodes97 @JoshJelliott97

Abstract

Background: Qualitative movement screening tools provide a practical method to assess mechanical patterns associated with potential injury development. Biomechanics play a role in hamstring strain injury and are recommended as a consideration within injury screening and rehabilitation programs. However, to date, there are no methods available for the in-field assessment of sprint running mechanics associated with hamstring strain injuries.

Purpose: To investigate the intra- and inter-rater reliability of a novel screening tool assessing in-field sprint running mechanics titled: The Sprint Mechanics Assessment Score (S-MAS). A secondary purpose was to present normative S-MAS data to facilitate interpretation of performance standards for future assessment uses.

Study Design: Cross sectional Study

Methods: Maximal sprint running trials (35-m) were recorded from 136 elite soccer players using a slow-motion camera. All videos were scored using the S-MAS by a single assessor. Videos from 36 players (18 male, 18 female) were rated by two independent assessors blinded to each other's results to establish inter-rater reliability. One assessor scored all videos in a randomised order 1 week later to establish intra-rater reliability. Intraclass correlation coefficients (ICC) based on single measures using a two-way mixed effects model with absolute agreement with 95% confidence intervals (95%CI) and Kappa coefficients with percentage agreements were used to assess reliability of the overall score and individual score items respectively. T-Scores were calculated from male and female group means and standard deviation to present normative data values. Mann Whitney-U and Wilcoxon Signed Rank test were used to assess for between-sex differences and between-limb differences respectively.

Results: The S-MAS showed good intra-rater (ICC = .828, 95%CI = .688-.908) and inter-rater (ICC = .799, 95%CI = .642-.892) reliability, with a standard error of measurement of 1 point. Kappa Coefficients for individual score items demonstrated moderate to substantial intra- and inter-rater agreement for most parameters, with percentage agreements ranging from 75% to 88.8% for intra- and 66.6% to 88.8% for inter-rater reliability. No significant sex differences were observed for overall score with mean values of 4.2 and 3.8 for male and females respectively (p = .27).

Conclusion: The S-MAS is a novel, new tool developed for assessing sprint running mechanics associated with lower limb injuries in male and female soccer players. The reliable and easy-to-use nature of the S-MAS means this method can be integrated to practise, potentially aiding future injury screening and research looking to identify individuals who may demonstrate mechanical patterns potentially associated with hamstring strain injuries.

Key Terms: Movement quality; screening; qualitative screening; soccer; rehabilitation; hamstring; biomechanics

What is known about the subject:

- Sprint running is associated with hamstring strain injuries with some evidence suggesting there may be a role of sprint running kinematics.
- Assessment of sprint running mechanics is traditionally limited to three-dimensional motion capture technology.
- There are no current in-field screening tools for the assessment of sprint running mechanics associated with potential hamstring strain injuries.

What this adds to existing knowledge:

- This study presents a new method for the in-field assessment of sprint running mechanics: the Sprint Mechanics Assessment Score (S-MAS).
- The S-MAS is easy to use with good intra- and inter-rater reliability.
- The normative values presented aid clinical interpretation of the S-MAS for future applied use.

Introduction

Hamstring strain injuries (HSI) are the most common injury to affect team-based sports accounting for up to 24% of injuries in soccer.[12] The primary mechanism of HSI appears to be during maximal velocity sprint running, with up to 48% of all HSIs reported to occur at this timepoint.[16] Whilst several risk factors exist for HSI (i.e., age, previous injury, eccentric hamstring strength and muscle architecture),[15] recent qualitative studies highlight that practitioners and coaches believe sprint running biomechanics are one of a variety of factors which may influence injury development.[14,22] With specific regards to sprint running mechanics, an over-stride gait pattern, reduced lumbopelvic control, anterior pelvic tilt and excessive back-side mechanics are some of the most common kinematic features thought to influence the risk of HSI.[22]

Several investigations provide empirical data to support the association between sprint mechanics and HSI occurrence.[13,24,42,43] Schuermans, Van Tiggelen, Palmans, et al. [43] reported 4 soccer players who sustained a HSI demonstrated increased anterior pelvic tilt during the swing phase of running when compared to controls, whilst additional studies have reported individuals who sustained HSIs to display features including increased trunk side flexion, [24] altered trunk muscle activity, [13,42] and increased trunk flexion angles at touchdown.[41] These kinematic features may increase hamstring stretch resulting in greater tissue strain at key phases of the gait cycle when muscle forces are high.[5]

Based on the associations between biomechanics and HSIs, authors have suggested that sprint running mechanics, and subsequent technique modification, should be considered within injury prevention and rehabilitation programs.[11,28] However, current assessment methods are generally restricted to three-dimensional motion capture technology (3DMoCap). Although 3DMoCap is considered the gold standard of biomechanical assessments, the use of such technology is both costly and time-consuming, often restricted to small laboratory spaces. Consequently, it is not feasible for practitioners to conduct in-field assessments of sprint running mechanics, particularly for the screening of large numbers of athletes in team-based sports. Therefore, practitioners are currently unable to assess for, and identify individuals who may demonstrate sub-optimal movement patterns which could potentially influence tissue stress and strain, and possible HSI, and are unable to evaluate the effectiveness of interventions targeting sprint running mechanics.

Qualitative movement screening tools using 2-D video cameras offer a practical approach to in-field movement assessment, particularly movement quality deficits linked to potentially injury occurrence. For example, several methods have been developed across a variety of activities including the Landing Error Scoring System (LESS),[38] the Cutting Movement Assessment Score

(CMAS)[10] and the Qualitative analysis of Single Leg Loading (QASLS).[19] These tools have proven to be reliable methods of movement assessment which can be easily integrated into practice and utilised in the injury risk screening, mitigation, and rehabilitation process.[9,20,21] However, these assessment tools are designed to identify mechanical patterns associated with non-contact knee injuries. To date, there are no field-based screening methods for the assessment of sprint running mechanics associated with HSIs.

Based on the association between, and practitioner belief that sprint running mechanics influence HSI, a qualitative movement screening tool may prove a practical approach to the assessment of sprint running mechanics associated with HSI. Creation of such a tool could ultimately assist in large mass injury screening and rehabilitation processes, enabling practitioners to identify individuals who demonstrate mechanical patterns associated with potential HSI whereby individualised gait interventions and technique modification programmes can be developed.

Therefore, the primary aim of this paper was to investigate the intra- and inter-rater reliability of a novel, easy-to-use, in-field method of assessing sprint running mechanics associated with HSI: the Sprint Mechanics Assessment Score (S-MAS). A secondary aim was to present normative benchmarking data from a larger dataset of participants to aid future interpretation of S-MAS values. Based on reliability results of previous qualitative screening tools[10,38] it was hypothesised that the S-MAS would demonstrate good to excellent intra- and inter-rater reliability.

Methods

Participants

A total of 136 elite soccer players (54 female, 82 male) were recruited from 10 clubs (7 male, 3 female) in the English Football League. Participants were classified as either tier 3 (Highly trained/National Level) or tier 4 (Elite/ International Level) according to a recent participant classification framework proposed by McKay et al.[30] with participant characteristics presented in Table 1. A subset of 36 participants (18 female 18 male) were used to establish the intra- and inter-rater reliability of the S-MAS (Table 1). Reliability sample size was based on a prior power calculation described by Bonett [1] for an expected level of reliability of 0.85, precision of 0.1, confidence intervals set to 95% and a total of 2 raters, indicating 31 participants were required to achieve sufficient statistical power. All participants were injury free and cleared for full training and competition prior to data collection, participants were excluded from data analysis if they had a recent injury or surgery within the last 12 months. Goalkeepers were also excluded from analysis due to their lack of regular exposure to sprint running. Ethical approval was granted from the local ethics committee and all participants provided written informed consent prior to participation.

Table 1: Participant characteristics. Values are presented as means (standard deviation)

	All Data		**Reliability Data**	
	Male (*n* = 82)	**Female (*n* = 54)**	**Male (*n* = 18)**	**Female (*n* = 18)**
Age (years)	22.0 (4.5)	24.1 (4.5)	24.6 (5.4)	23.7 (4.9)
Mass (kg)	78.6 (7.8)	62.2 (6.2)	77.8 (7.9)	60.9 (8.2)
Height (cm)	182.6 (5.6)	166.3 (6.2)	181.2 (4.9)	163.7 (5.5)
Maximal Running Velocity (m/s)	8.5 (1.2)	7.0 (0.6)	8.7 (1.3)	6.5 (0.5)

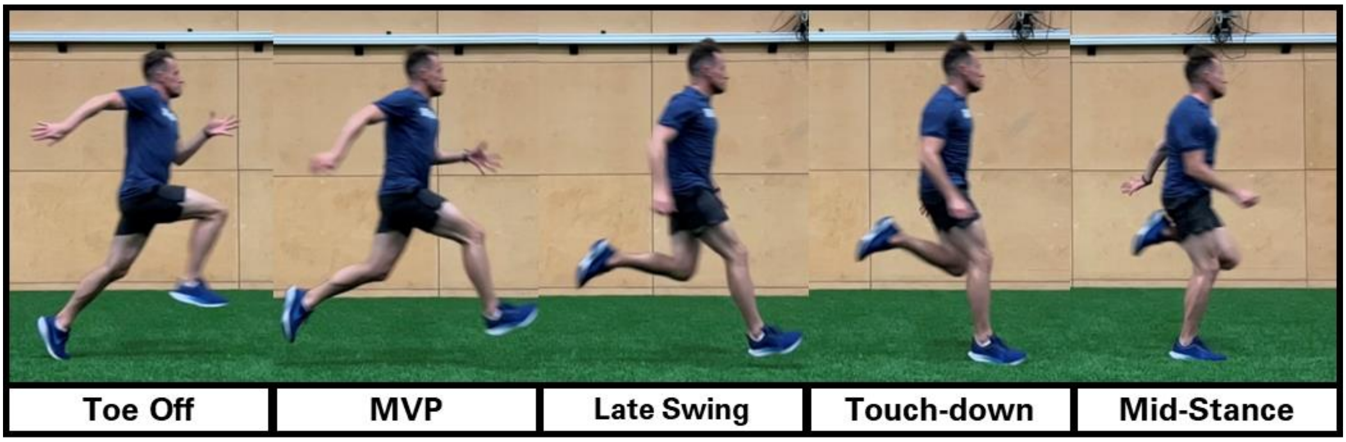
Data Collection

All participants completed 2 maximum velocity 35 meter sprint running trials which were recorded using a slow motion camera sampling at 240fps (iPhone 13 pro, Apple). Data were collected between the period of June to September. Two pairs of photocell timing gates (Witty Photocells, Micrograte, USA) (placed at approximate hip height) were positioned across the capture volume between 25 – 30 meters used to monitor maximal running velocity. The 25 – 30m section was selected as this marks the end of the sprint transition phase therefore reflecting maximal velocity running mechanics (particularly for team-sport athletes who attain maximum velocity earlier compared to track sprinters).[35] The camera was positioned on a tripod at a height of 0.8m and distance of 7m perpendicular to the capture volume. Participants completed a standardised “RAMP” (raise, activate, mobilise, potentiate) warm-up led by individual club sports science team prior to completing two maximum effort sprint running trials. The warm-up consisted of low intensity jogging, dynamic mobility and running drills, followed by single progressive running strides at 80% and 90% of maximum effort and took a total of 10 – 15 minutes. All running trials were completed with participants wearing their own sport specific footwear on a synthetic artificial field turf or grass football pitch. A sub-group of 25 male participants completed three max effort running trials. The additional max effort running trial allowed for data collection of two videos recorded form the same side, subsequently used to determine inter-trial reliability of the S-MAS.

S-MAS tool

The S-MAS is a 12-item qualitative movement screening tool assessing the overall movement quality of an individual’s sprint running mechanics (Table 2 & Supplementary File 1). Using a slow-motion video, sprint running trials are segmented into phases of the gait cycle, similar to those described in the ALTIS kinogram method[32] (Figure 1 & Table 2). Movement patterns are then evaluated and rated against 12 criteria using a dichotomous scoring system for the presence (1 point) or absence (0 point) of select kinematic features. Scores are summed with a total score of 0 indicating optimal mechanics and 12 sub-optimal, with higher scores generally representative of poorer technique.

Figure 1: Visual representation of phases of the sprint cycle. MVP: maximal vertical projection.



The score was developed following a three-step process. First, individual items forming the score were selected based on findings from published qualitative investigations which explored the opinions of coaches and practitioners on kinematic features influencing HSI.[22] Second, a literature review was conducted to identify parameters with a mechanistic link influencing hamstring tissue stress/strain, and/or prior published associations with HSI.[2] This led to an initial draft of the S-MAS, with operational definitions used to visualise parameters based on values published in prior literature detailing maximal velocity sprint running mechanics.[29,44] Finally, separate consultations were conducted with practitioners and coaches to establish agreements or disagreements with any of the included parameters and refine operational definitions of the criteria. This led to the final S-MAS detailed in table 2 & supplementary file 1.

Table 2: The Sprint Mechanics Assessment Score (S-MAS).

Phase	Parameter & Description	Score ***Score: Yes = 1, No = 0***	
		Left	**Right**
Contralateral Toe off *Point immediately prior to the contralateral foot leaving the ground*	**Trailing limb extension** *Does the athlete look to be in excessive extension? This may be characterised by the trailing hip oriented at $\geq 45^{o}$ from the vertical, combined with a fully extended knee.*		
Maximal Vertical Projection (MVP) *Mid-point between toe off and touch-down. Pelvis is at highest point in the flight phase.*	**Back Kick** *Is the heel of the trailing limb above the calf of the trailing leg? Shin should not be higher than parallel with the floor.*		
	Trunk & Pelvis Rotation *Do they look to rotate excessively through the trunk? This may appear as large arm movements, trunk twisting with the upper arm and shoulder visible on the far side of the body.*		
Late Swing *The point of maximal knee extension during the swing phase*	**Thigh Separation** *Is the knee of the trailing leg behind the gluteus muscles?*		
MVP to Late Swing	**Lumbar extension / Anterior Pelvic Tilt** *At any point between MVP and late swing, does the athlete look to be in anterior pelvic tilt or lumbar extension?* *This may look like excessive arching of the lower back, elevated chest or "bum behind the body"*		
Touch-down *Point of first contact with the ground*	**Forward lean** *Do they look to have an increased forward lean? This may look $>15^{o}$ if a line drawn from the vertical compared to one from the greater trochanter to the C7 vertebrae*		
	Lumbar extension / Anterior Pelvic Tilt *Does there look to be an increase in anterior pelvic tilt or lumbar extension?* *This may look like excessive arching of the lower back or "bum behind the body"*		
	Thigh Separation *Is the gap between the thighs $>20^{o}$ or the trailing knee behind the back?*		
	Foot Contact v Centre of Mass (CoM) Distance *A line drawn horizontally from the position of foot contact to the centre of mass, is there space for another foot?*		
	Shin Angle *Does the shin look to be extended? This may appear as an ankle joint centre positioned in front of the knee*		
	Foot Inclination *Is there a visible gap between the forefoot & the floor, or heel & the floor? (Excessive heel strike or forefoot strike)*		
Mid Stance *The point where the pelvis is positioned directly over the ankle joint*	**Vertical Collapse / Mid-stance collapse** *Is there increased knee flexion/ ankle dorsiflexion? This may look like the subject is "sinking" into the stride, "sitting down", or the knee is translating over the toes with the foot flat*		
TOTAL SCORE			

Intra- and Inter-rater Reliability

For the reliability assessment 2 raters first attended a 2-hour training session on how to use the S-MAS. Raters included one physiotherapist (CB) and one strength and conditioning coach (TDS), both with more than 10 years' experience in their respective field and doctorates (PhD) in biomechanics. The 2-hour training session included discussion of score items and definitions along with 3 practice trials where videos were first independently scored followed by a discussion of agreements and disagreements in ratings. Videos were viewed by raters in Kinovea (v0.9.5 for Windows; Bordeaux, France) software which allowed videos to be played at various speeds and frame-by-frame. Gait phases were identified in accordance with descriptors provided on the S-MAS, with practitioners permitted to move frames forwards and backwards to aid identification of parameters. All practice videos were excluded from the final reliability testing. Following the training session both raters separately scored all 38 videos against the S-MAS. Two weeks later, one rater (TDS) scored all videos again in a randomised order, blinded to original scores, similar to methods outlined in previous studies.[36,38] Screening of one video trial took ~2 minutes.

Statistical analyses

Statistical tests were performed in SPSS (SPSS v26 Inc, Chicago, IL). S-MAS values were first analysed for data normality and homogeneity of variances using Shapiro-Wilk test and Levine's test. Due to non-normal distribution of data, Mann Whitney-U test was used to assess for between-sex differences and Wilcoxon Signed Rank test for between-limb differences in S-MAS values. One-way analysis of variance was used to assess for differences between playing positions with positions separated into central defenders, wide defenders, central midfielders, wide midfielders and forwards.

To facilitate practical use and interpretation of S-MAS values, T-Scores were calculated to establish normative benchmarks for individual profiling, as described in prior publications.[31,45] Sample sizes of 50 – 85 have been suggested as the minimum required to achieve stable means and standard deviations necessary for establishing normative data.[39] Z-scores were initially calculated using the formula *z = (S-MAS value – group mean)/group SD*. Z-scores were then converted to T-scores using the formula *t = (z x 10) + 50*. T-scores of 50 are equivalent to the mean value, scores of ≥60 are 1SD above the mean and scores of below ≤40 are 1SD below the mean. T-Scores were interpretated as <40 excellent, ≥ 40 - ≤45 good, >45 - ≤55 average, >55 - ≤60 poor and >60 to ≤80 very poor and >80 extremely poor.[31]

Intra, inter-rater, and inter-trial reliability of the overall S-MAS was assessed using Intraclass Correlation Coefficients (ICC) based on single measures using a two-way mixed effects model with absolute agreement with 95% confidence intervals (95%CI) in accordance with methods outlined by Koo & Li.[25] Standard error of measurement (SEM) was calculated as SD*√(1-ICC). ICC values of <0.5, 0.5 – 0.75, 0.75 – 0.9 and >0.9 were interpretated as poor, moderate, good and excellent respectively.[25] Reliability of individual items on the S-MAS were assessed using Cohen's Kappa statistic and percentage agreements as described in previous literature.[6] Cohen's Kappa values were interpreted as <0: poor, 0 – 0.20 slight, 0.21 – 0.40 fair, 0.41 – 0.60 moderate, 0.61 – 0.80 substantial, 0.81 – 1.00 almost perfect.[27] Percentage agreements were interpreted as ≤50% poor, 51 – 79% moderate and ≥80% excellent.[36]

Results

ICC values for intra- and inter-rater reliability showed good reliability with values of .828 (95%CI: .688 - .908) and .799 (95%CI: .642 - .892) respectively with a SEM of 1 point. Based on Kappa coefficients for individual items, 11 out of 12 parameters demonstrated moderate to substantial intra-rater reliability and 9 out of 12 demonstrated moderate to substantial inter-rater reliability (Figure 2). Percentage agreements ranged from 75.0% to 88.8% for intra- and 66.6% to 88.8% for inter-rater reliability, demonstrating moderate to excellent agreement for all parameters (Figure 3). For inter-trial reliability mean S-MAS value for trial 1 was 4.1 (SD: 2.3) and 4.0 (SD: 2.0) for trial two. ICC was .74 (95%CI: .492 - .877) with a SEM of 1 point.

No significant difference was found between male and female S-MAS with mean values of 4.2 (SD: 2.6) and 3.8 (SD: 2.5) respectively (p = .27). Significant between-limb differences were observed between right (mean: 4.5, SD: 2.7) and left limbs (mean: 4.0, SD: 2.7) (p<.01, 95%CI: .09 - .81). No significant differences were observed between playing position ($p = .664$) (Figure 4). Using T-scores and benchmarking, S-MAS descriptors are presented in figure 5.

Figure 2: Intra- and Inter-rater Kappa coefficient for individual S-MAS parameters

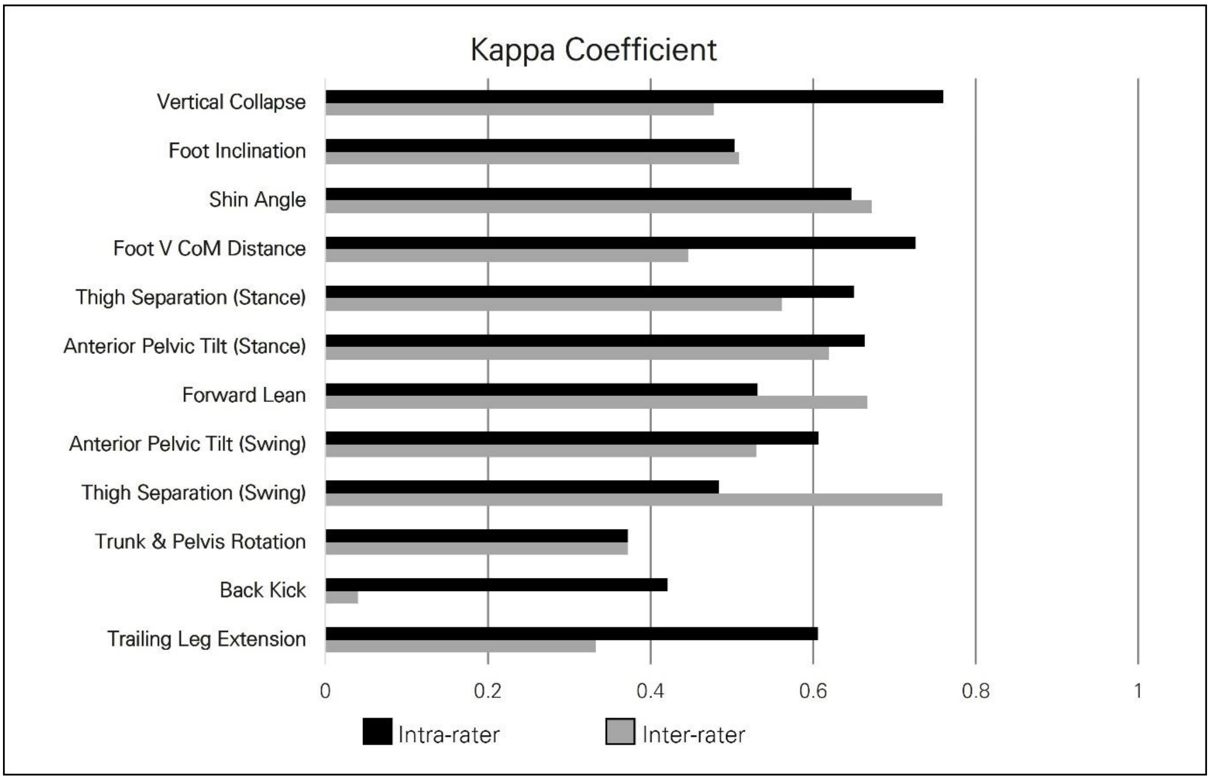


Figure 3: Intra- and Inter-rater percentage agreement for individual S-MAS parameters

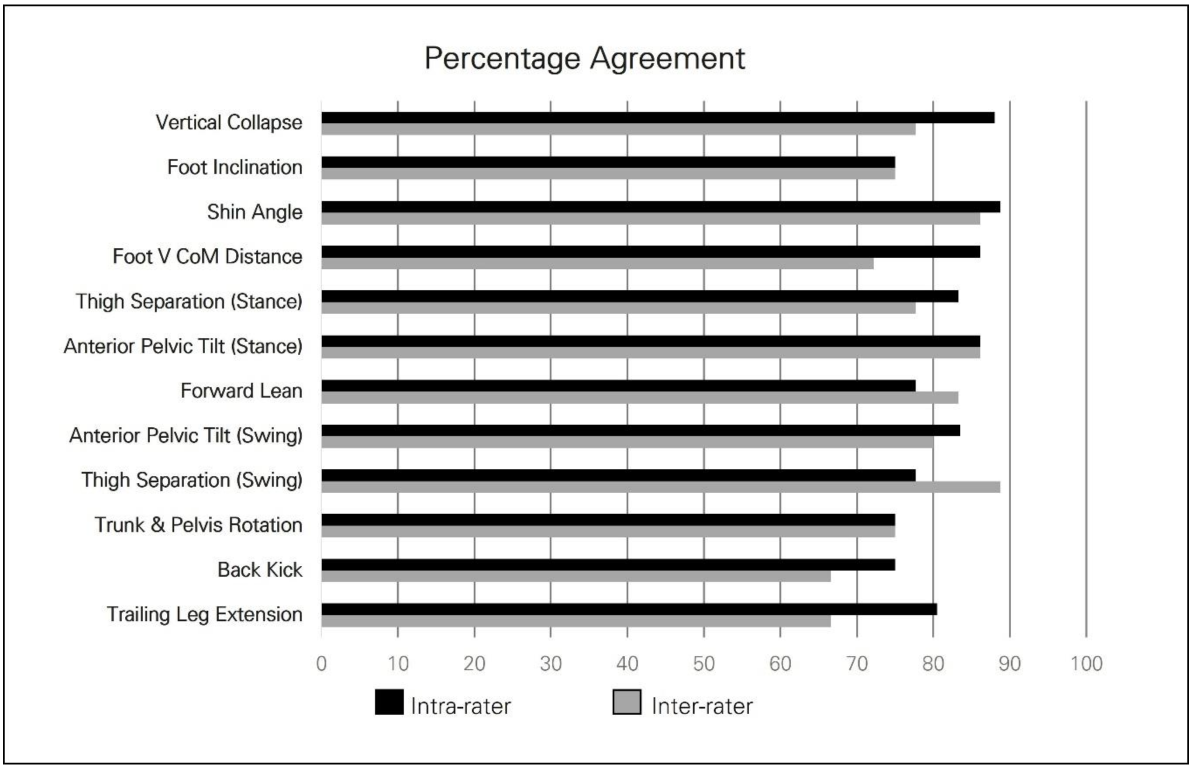


Figure 4: Box plots for S-MAS values based on playing position. Solid line within the box depicts the median value, top and bottom of the box indicate the interquartile range, whiskers depict the minimum and maximum values, the cross indicates the mean value.

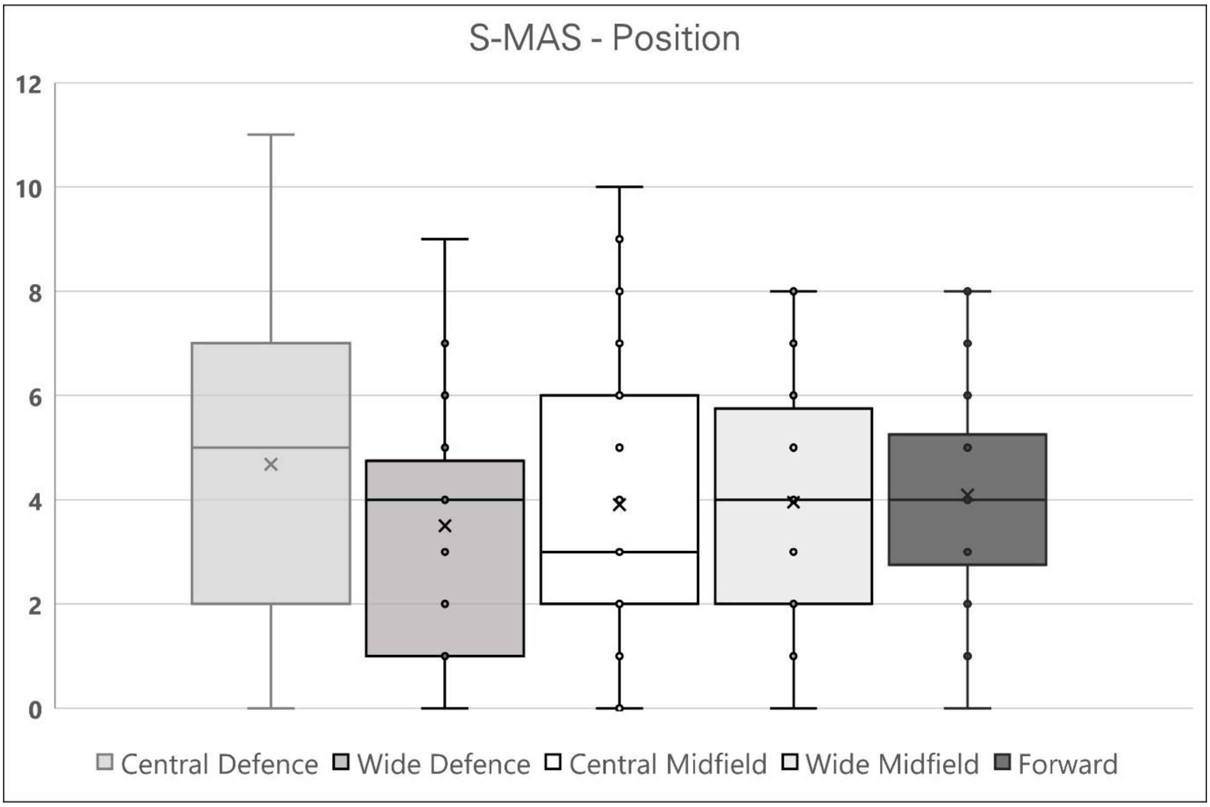


Figure 5: Normative benchmarking for S-MAS interpretation based on T-Scores

Description	S-MAS	T-Score
Excellent	0	33.8
Excellent	1	37.7
Good	2	41.5
Average	3	45.4
Average	4	49.2
Average	5	53.1
Poor	6	57.0
Very Poor	7	60.8
Very Poor	8	64.7
Very Poor	9	68.6
Very Poor	10	72.4
Very Poor	11	76.3
Extremely Poor	12	80.1

Discussion

The primary aim of this study was to investigate the intra- and inter-rater reliability of a novel in-field method of assessing sprint running mechanics associated with HSI: the Sprint Mechanics Assessment Score (S-MAS). As hypothesised, results highlight that the S-MAS has both good intra- and inter-rater reliability, with no significant differences observed in mean scores between male and female soccer players, or playing positions. Therefore, findings of the present study indicate that the S-MAS is a reliable tool which can be used for in-field assessment of sprint running mechanics in both male and female populations.

It is widely acknowledged that HSI development is influenced by the interaction between multiple factors.[3] Eccentric hamstring strength, muscle architecture and material properties, age, high speed sprint running exposure, fixture congestion, fatigue, recovery and training environment are some of the many factors acknowledged by coaches, practitioners and research to play a role in HSI.[3,14,15] Additionally, biomechanical factors are believed to play a role in the development of HSI's within team sports.[14,22] Whilst data from both prospective and retrospective investigations support the associations between the two,[8,43] this is primarily through studies utilising 3DMoCap. This technology is undoubtably the gold standard of biomechanical assessments; however, it lacks clinical utility in-field, and is not conducive for large mass athlete screening. The costly and time-consuming nature of 3DMoCap limits the ability to recruit large sample sizes in research studies and restricts the practical assessment of individuals in team sport settings. Addressing this limitation, the S-MAS offers a practical alternative to 3DMoCap by simply using the high-speed recording capabilities of a smart device (which is a common default feature of most tablet and smart phone technology) and free video viewing software. Thus, allowing practitioners and coaches to quickly assess sprint running mechanics of both individuals and teams, identifying those who may demonstrate kinematic patterns associated with HSI's.

Although some literature supports the association between isolated biomechanical parameters and HSI, this relationship can often be conflicting.[24,43] Since muscle injuries occur due to the interaction between stress and strain,[23] it seems logical that a combination of mechanical patterns contribute to HSI occurrence. This is reflected in multiple case reports where injury onset was associated with multiple mechanical features thought to influence overall tissue strain.[18,41]

The S-MAS utilises a composite score which aims to reflect the collective contribution of multiple biomechanical parameters on potential HSI risk. This is a similar approach to existing movement assessment tools such as the LESS[38] and CMAS[10] in relation to knee joint loads associated with ACL injury risk. The composite score approach intends to shift practitioner focus away from single parameters and quantify the overall severity of gait, building confidence in whether observed mechanical patterns are sufficient to influence injury.

The composite nature of the S-MAS is important from a reliability perspective, as individual items often have lower reliability compared to the total score. In a prior study investigating the reliability of a qualitative analysis for endurance running, 5 parameters out of 15 demonstrated fair to poor inter-rater reliability,[40] indicating potential variations in interpretation of isolated kinematic variables. In the present study, greater inter-rater reliability was observed, but 3 parameters (back kick, trunk rotation, trailing leg extension) still showed poor to fair inter-rater agreement based on Kappa coefficients (Figure 2) (it is important to note these parameters showed moderate percentage agreements, Figure 3). Conversely, the overall S-MAS values demonstrate good inter- and intra-rater reliability. This suggests that the overall score can be more confidently relied upon when identifying individuals who may demonstrate potential "high-risk" movement patterns and when evaluating the response to interventions.

While acknowledging the importance of the overall score, there is still potential value gained from the interpretation of individual score items. Individual score items represent different aspects of sprint running mechanics and can aid practitioners in identifying specific mechanical factors contributing to the overall movement quality. For example, within the S-MAS, score items of "back-kick", "thigh-separation angle" and "trailing leg extension" represent back-side running mechanics,[29] while other items represent altered lumbo-pelvic control and/ or overstride mechanics. Identifying these sub-components allows for the development of specific, tailored movement interventions which have been proven capable of modifying movement patterns associated with HSI.[33,34] Therefore, both the composite score and individual items play complementary roles in using the S-MAS; through identification of potentially "higher-risk" individuals, development of targeted interventions and evaluation of overall change.

In the present study normative ranges were calculated using T-scores from the entire dataset to aid clinical interpretation of S-MAS values. This approach is commonly used for normative data benchmarking in sports performance and injury screening,[10,38] and is similar to methods used for movement assessment scores such as the LESS and CMAS. Based on the T-scores presented, S-MAS values of ≤ 1 were considered as excellent, 2 as good, 3 – 5 as average, 6 as poor, ≥ 7 as very poor and 12 as extremely poor. Across other movement assessment scores, Padua, Marshall, Boling, et al. [38] used quartile ranges to separate LESS scores into severity categories, later reporting values >5 (considered moderate to poor) to be associated with greater incidence of future ACL injuries.[37] Similarly, Dos'Santos, McBurnie, Donelon, et al. [10] reported CMAS scores above 7 to be associated with greater knee joint loading parameters compared to scores of 3 or less. Therefore, the use of composite scores and normative ranges may aid clinical interpretation of S-MAS values, assisting practitioners in the identification of individuals who demonstrate potential "higher-risk" movement patterns and benefit from targeted gait interventions. However, at present, it is important to be cautious with this interpretation, as further work is required to establish the association between the S-MAS and HSI's.

Comparing results from the present study to those of previous authors, ICC values for reliability of the S-MAS appear similar to other established movement assessment scores. The LESS score has been shown to have ICC values of .91 and .84 for intra- and inter-rater reliability whilst the CMAS has shown ICC values of .946 and .690.[10,38] This is similar to the present scores of .828 and .799 for intra and inter-rater reliability. The S-MAS's good reliability could be attributed to several factors. Firstly, consistent with previous researchers, raters were provided with a training session prior to scoring videos and had a background in biomechanics.[10,38] Whilst it is unknown whether practitioner training improves reliability[26] it potentially allows for consistency in the application of the S-MAS and has been anecdotally suggested to improve inter-rater reliability.[38,47] Second, the S-MAS utilises dichotomous ratings for individual items and clear definitions aiding visualisation of parameters. The use of dichotomous ratings has been shown to improve both within and between practitioner agreement in visual assessment of movement patterns, removing ambiguity in the identification of specific mechanical features.[4,47] Finally, the S-MAS utilises predominantly sagittal plane movements, which is both more pragmatic for data capture and allows easier screening against the established S-MAS criteria. Therefore, it is possible that the combined use of practitioner training along with clear assessment criteria and dichotomous rating system contribute to the overall reliability of the S-MAS.

Whilst there were no significant differences between male and female soccer players, significant between-limb differences were observed when comparing right and left limbs. However, the mean difference of .45 and 95% confidence intervals of .09 - .81 are less than the standard error of measurement of 1 point for the S-MAS. Therefore, the between limb differences fall within the range that can be considered due to inter-trial variability of kinematic patterns. For future practical interpretation of differences in S-MAS scores, it is recommended to ensure that differences exceed the standard error of measurement for differences to be considered potentially meaningful.

Limitations

There are limitations of the present work that should be acknowledged. One being that only two raters were used and both could be considered expert raters with more than 10 years' experience in both biomechanics and their respective professions. That said, the rater used for the intra-rater reliability could be considered a novice user of the score. Whilst involved in the S-MAS development process, they had no experience utilising the score prior to the reliability testing. Although a prior study by Whatman, Hume and Hing [48] suggested more experienced raters demonstrate greater intra- and inter-rater reliability when visually scoring movement compared to novices, these findings are equivocal. Several further studies have reported good to excellent intra- and inter-tester reliability amongst novice compared to experienced raters,[7,17,46] with one study utilising the LESS (a composite score similar to the current work) reporting excellent intra and inter-tester of the LESS with ICCs of .835 amongst novice raters.[36] Therefore, we would hypothesise similar findings when comparing reliability of the S-MAS between larger groups of practitioners; particularly if training is conducted to standardise the use of the S-MAS score. However, we acknowledge that future work should consider evaluating the inter-tester reliability of the S-MAS between novice/ inexperienced practitioners and practitioners of different professions (i.e., sports scientists, doctor, coach etc).

An additional limitation is that the reliability was assessed using a single running trial. This was due to the pragmatic nature of collecting repeat maximal velocity sprint running trials in elite soccer players, where in many instances the collection of multiple trials is not feasible. Consequently, this may reduce the overall reliability when using ICC single measures. However, despite this ICC values were still good, but may potentially be improved if S-MAS scores are averaged across multiple sprint trials. Therefore, this should be a consideration for future research and for practical use of the S-MAS.

Finally, the data presented in the current study is of individuals who were injury free at the time of testing. Further work is required to investigate whether the S-MAS differs between individuals with recent HSIs and whether there are associations to future injury development.

Conclusion

The present study highlights that the S-MAS is a reliable tool for the in-field assessment of sprint running mechanics in both male and female populations. The easy-to-use nature of the S-MAS means this can be easily integrated into practise to permit large mass screening of athletes at the community to elite level. The presented normative benchmarking values may aid in the applied use of the S-MAS facilitating the identification of individuals who demonstrate potential "higher-risk" sprint running mechanics and may benefit from interventions targeted towards optimising movement quality.

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