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# The Sprint Mechanics Assessment Score

## A Qualitative Screening Tool for the In-field Assessment of Sprint Running Mechanics

Christopher Bramah,<sup>\*†‡</sup> PhD , Jonas Tawiah-Dodoo,<sup>§</sup> BSc, MSc, Samantha Rhodes,<sup>†‡||</sup> BSc, MSc , Joshua D. Elliott,<sup>‡||¶</sup> BSc, MSc, and Thomas Dos'Santos,<sup>\*\*\*</sup> PhD  
*Investigation performed at School of Health & Society, University of Salford, Salford, Manchester, UK*

**Background:** Qualitative movement screening tools provide a practical method of assessing 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, no methods are available for the in-field assessment of sprint running mechanics associated with hamstring strain injuries.

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

**Study Design:** Cohort study (diagnosis); Level of evidence, 3.

**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 men and 18 women) were rated by 2 independent assessors blinded to each other's results to establish interrater reliability. One assessor scored all videos in a randomized order 1 week later to establish intrarater reliability. Intraclass correlation coefficients (ICCs) based on single measures using a 2-way mixed-effects model, with absolute agreement with 95% CI and kappa coefficients with percentage agreements, were used to assess the reliability of the overall score and individual score items, respectively. *T*-scores were calculated from the means and standard deviations of the male and female groups to present normative data values. The Mann-Whitney *U* test and the Wilcoxon signed-rank test were used to assess between-sex differences and between-limb differences, respectively.

**Results:** The S-MAS showed good intrarater (ICC, 0.828 [95% CI, 0.688-0.908]) and interrater (ICC, 0.799 [95% CI, 0.642-0.892]) reliability, with a standard error of measurement of 1 point. Kappa coefficients for individual score items demonstrated moderate to substantial intra- and interrater agreement for most parameters, with percentage agreements ranging from 75% to 88.8% for intrarater and 66.6% to 88.8% for interrater reliability. No significant sex differences were observed for overall scores, with mean values of 4.2 and 3.8 for men and women, respectively ( $P = .27$ ).

**Conclusion:** The S-MAS is a 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 that this method can be integrated into practice, potentially aiding future injury screening and research looking to identify athletes who may demonstrate mechanical patterns potentially associated with hamstring strain injuries.

**Keywords:** biomechanics; hamstring; movement quality; qualitative screening; rehabilitation; screening; soccer

Hamstring strain injuries (HSIs) are the most common injuries affecting team-based sports, accounting for up to 24% of injuries in soccer.<sup>12</sup> 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 time point.<sup>16</sup> Although several risk factors exist for HSIs (ie,

age, previous injury, eccentric hamstring strength, and muscle architecture),<sup>15</sup> recent qualitative studies highlight that practitioners and coaches believe sprint running biomechanics are 1 of a variety of factors that may influence injury development.<sup>14,22</sup> With specific regard to sprint running mechanics, an overstride gait pattern, reduced lumbo-pelvic control, anterior pelvic tilt, and excessive backside mechanics are some of the most common kinematic features thought to influence the risk of HSIs.<sup>22</sup>

Several investigations provide empirical data to support the association between sprint mechanics and HSI occurrence.<sup>13,24,42,43</sup> Schuermans et al<sup>43</sup> reported that 4 soccer



players who sustained an HSI demonstrated increased anterior pelvic tilt during the swing phase of running when compared with controls, while additional studies have reported players who sustained an HSI displayed features including increased trunk-side flexion,<sup>24</sup> altered trunk muscle activity,<sup>13,42</sup> and increased trunk flexion angles at touch-down.<sup>41</sup> These kinematic features may increase hamstring stretch, resulting in greater tissue strain at key phases of the gait cycle when muscle forces are high.<sup>5</sup>

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

Qualitative movement screening tools using 2-dimensional video cameras offer a practical approach to in-field movement assessment, identifying movement quality deficits linked to potential injury occurrence. For example, several methods have been developed across a variety of activities—including the Landing Error Scoring System (LESS),<sup>38</sup> the Cutting Movement Assessment Score (CMAS),<sup>10</sup> and the qualitative analysis of single-leg loading.<sup>19</sup> These tools have proved to be reliable methods of movement assessment that can be easily integrated into practice and utilized in the injury risk screening, mitigation, and rehabilitation process.<sup>9,20,21</sup> 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 assessing sprint running mechanics associated with HSIs.

Based on the association between sprint running mechanics and HSI, a qualitative movement screening tool may prove to be a practical approach to evaluating

sprint running mechanics which may influence HSI. The creation of such a tool could ultimately assist in large mass injury screening and rehabilitation processes, enabling practitioners to identify those who demonstrate mechanical patterns associated with potential HSI, whereby individualized gait interventions and technique modification programs can be developed.

Therefore, the primary aim of this study was to investigate the intra- and interrater 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). The secondary aim was to present normative benchmarking data from a larger data set of participants to aid future interpretation of S-MAS values. Based on reliability results of previous qualitative screening tools,<sup>10,38</sup> it was hypothesized that the S-MAS would demonstrate good to excellent intra- and interrater reliability.

## METHODS

### Participants

A total of 136 elite soccer players (54 women and 82 men) were recruited from 10 clubs (7 male and 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<sup>30</sup>; participant characteristics are presented in Table 1. A subset of 36 participants (18 women and 18 men) was used to establish the intra- and interrater reliability of the S-MAS (Table 1). The reliability sample size was based on a previous power calculation described by Bonett<sup>1</sup> 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 that 31 participants were required to achieve sufficient statistical power. All participants were injury-free and cleared for full training and competition before data collection; participants were excluded from data analysis if they had a recent injury or surgery within the past 12 months. Goalkeepers were also excluded from the analysis because of their lack of regular exposure to sprint running. Ethical approval was granted by the local ethics committee, and all participants provided written informed consent before participation.

\*Address correspondence to Christopher Bramah, PhD, School of Health & Society, University of Salford, Allerton Building, Frederick Road Campus, Salford, Manchester, M6 6PU, UK (email: c.a.bramah@salford.ac.uk) (Social Media: @chrisbramah).

<sup>†</sup>School of Health & Society, University of Salford, Salford, Manchester, UK.

<sup>‡</sup>Manchester Institute of Health & Performance, Manchester, UK.

<sup>§</sup>Speedworks Training, Stamford, UK.

<sup>||</sup>Nuffield Health, Manchester Institute of Health & Performance, UK.

<sup>\*</sup>Research Institute for Sport and Exercise, University of Canberra, Canberra, Australia.

<sup>#</sup>Department of Sport & Exercise Sciences, Manchester Metropolitan University, Manchester, UK.

<sup>\*\*</sup>Manchester Institute of Sport, Metropolitan University, Manchester, UK.

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TABLE 1  
Participant Characteristics<sup>a</sup>

	All Data		Reliability Data	
	Men (n = 82)	Women (n = 54)	Men (n = 18)	Women (n = 18)
Age, y	22 (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 speed, m/sec	8.5 (1.2)	7 (0.6)	8.7 (1.3)	6.5 (0.5)

<sup>a</sup>Values are presented as mean (SD).



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

## Data Collection

All participants completed 2 maximum-effort 35-m sprint running trials, which were recorded using a slow-motion camera sampling at 240 fps (iPhone 13 pro; Apple). Data were collected between June 2022 and September 2023. Two pairs of photocell timing gates (Witty Photocells; Micrograte), placed at approximately hip height, were positioned across the capture volume between 25 and 30 m to monitor maximal running speed. The 25- to 30-m section was selected as this marks the end of the sprint transition phase, reflecting maximal speed running mechanics—particularly for team sport athletes who attain maximum speed earlier than track sprinters.<sup>35</sup> The camera was positioned on a tripod at a height of 0.8 m and a distance of 7 m perpendicular to the capture volume. Participants completed a standardized raise, activate, mobilize, potentiate warm-up led by individual club sports science teams before completing 2 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 10 to 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 subgroup of 25 male participants completed 3 maximum-effort running trials. The additional maximum-effort running trial allowed for data collection of 2 videos recorded from 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) (see also the Appendix, available in the online version of this article). Using a slow-motion video, sprint running trials were segmented into phases of the gait cycle similar to those described in the ALTIS Kinogram method<sup>32</sup> (Figure 1 and Table 2). Movement patterns were 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 were summed with a total score of 0 indicating optimal mechanics and 12 suboptimal, with higher scores generally representative of poorer technique.

The score was developed after a 3-step process. First, individual items forming the score were selected based on findings from published qualitative investigations that explored the opinions of coaches and practitioners on kinematic features influencing HSI.<sup>22</sup> Second, a literature review was conducted to identify parameters with a mechanistic link influencing hamstring tissue stress/strain and/or previous published associations with HSI.<sup>2</sup> This led to an initial draft of the S-MAS, with operational definitions used to visualize parameters based on values published in previous literature detailing maximal velocity sprint running mechanics.<sup>29,44</sup> 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

TABLE 2  
The Sprint Mechanics Assessment Score<sup>a</sup>

Phase	Parameter & Description	Score: Yes = 1, No = 0	
		Left	Right
Contralateral toe-off The point immediately before the contralateral foot leaving the ground	Trailing limb extension Does the athlete appear to be in excessive extension? This may be characterized by the trailing hip oriented at $\geq 45^\circ$ from the vertical, combined with a fully extended knee.		
MVP Midpoint between toe-off and touch-down; pelvis is at its 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 and pelvic rotation Does the athlete appear to rotate excessively through the trunk? This may appear as large arm movements or 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 gluteal muscles?		
MVP to late swing	Lumbar extension/anterior pelvic tilt At any point between MVP and late swing, does the athlete appear to be in anterior pelvic tilt or lumbar extension? This may look like excessive lower back arching, elevated chest, or “bum behind the body.”		
Touch-down Point of first contact with the ground	Forward lean Does athlete appear to have an increased forward lean? This may look $>15^\circ$ if a line is drawn from the vertical compared with one from the greater trochanter to the C7 vertebra. Lumbar extension/anterior pelvic tilt Does there look to be an increase in anterior pelvic tilt or lumbar extension? This may look like excessive lower back arching or “bum behind the body.” Thigh separation Is the gap between the thighs $>20^\circ$ or the trailing knee behind the back? Foot contact vs CoM distance A line is drawn horizontally from the position of foot contact to the CoM. Is there space for another foot? Shin angle Does the shin look to be extended? This may appear as an ankle joint center in front of the knee. Foot inclination Is there a visible gap between the forefoot and the floor, or the heel and the floor (excessive heel strike or forefoot strike)?		
Midstance The point where pelvis is positioned directly over the ankle joint	Vertical collapse/midstance collapse Is there increased knee flexion/ankle dorsiflexion? This may look like the athlete is “sinking” into the stride, “sitting down,” or the knee is translating over the toes with the foot flat.		
Total score			

<sup>a</sup>CoM, center of mass; MVP, maximal vertical projection.

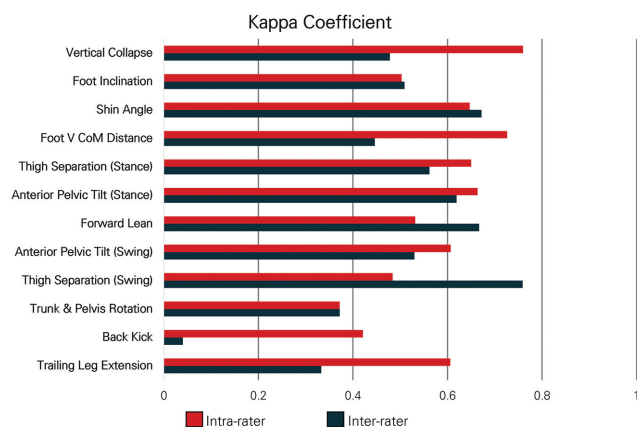
criteria. This led to the final S-MAS detailed in Table 2 and the Appendix (available online).

#### Intra- and Interrater Reliability

For the reliability assessment, 2 raters first attended a 2-hour training session on how to use the S-MAS. Raters included 1 physical therapist (C.B.) and 1 strength and conditioning coach (T.D.S), both with  $>10$  years of

experience in their respective field and a PhD in biomechanics. The 2-hour training session included a discussion of score items and definitions and 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 (Version 0.9.5 for Windows) 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 forward





**Figure 2.** Intra- and interrater kappa coefficient for individual Sprint Mechanics Assessment Score (S-MAS) parameters. CoM, center of mass. V, versus.

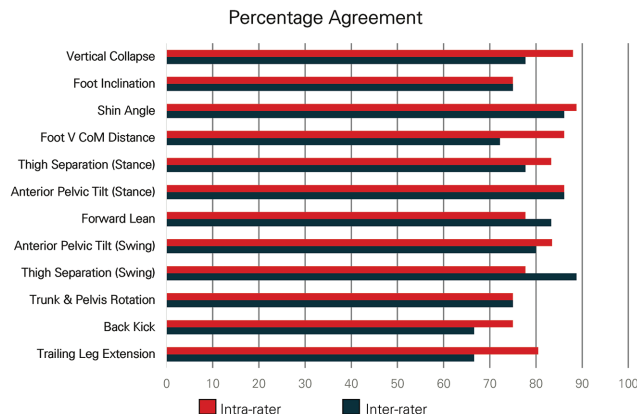
and backward to help identify the parameters. All practice videos were excluded from the final reliability testing. After the training session, both raters separately scored all 36 videos against the S-MAS. Two weeks later, 1 rater (T.D.S.) scored all videos again in a randomized order, blinded to original scores, similar to methods outlined in previous studies.<sup>36,38</sup> Screening of 1 video trial took ~2 minutes.

## Statistical Analysis

Statistical tests were performed in SPSS Version 26 (IBM). S-MAS values were first analyzed for data normality and homogeneity of variances using the Shapiro-Wilk test and the Levine test. Because of the non-normal distribution of data, the Mann Whitney *U* test was used to assess between-sex differences, and the Wilcoxon signed-rank test was used to assess between-limb differences in S-MAS values. One-way analysis of variance was used to evaluate differences between playing positions, with positions separated into central defenders, wide defenders, central midfielders, wide midfielders, and forwards.

*T*-scores were calculated to establish normative benchmarks for individual profiling, as described in previous publications, to facilitate practical use and interpretation of S-MAS values.<sup>31,45</sup> Sample sizes of 50 to 85 have been suggested as the minimum required to achieve stable means and standard deviations for establishing normative data.<sup>39</sup> *z* scores were initially calculated using the following formula:  $z = (S\text{-MAS value} - \text{group mean}) / \text{group SD}$ . *z* scores were converted to *T*-scores using the formula  $T = (z \times 10) + 50$ . *T*-scores of 50 are equivalent to the mean value, scores of  $\geq 60$  are 1 SD above the mean, and scores of below  $\leq 40$  are 1 SD below the mean. *T*-scores were interpreted as  $<40$  excellent,  $\geq 40$  to  $\leq 45$  good,  $>45$  to  $\leq 55$  average,  $>55$  to  $\leq 60$  poor,  $>60$  to  $\leq 80$  very poor, and  $>80$  extremely poor.<sup>31</sup>

Intrarater, interrater, and intertrial reliability of the overall S-MAS was assessed using the intraclass



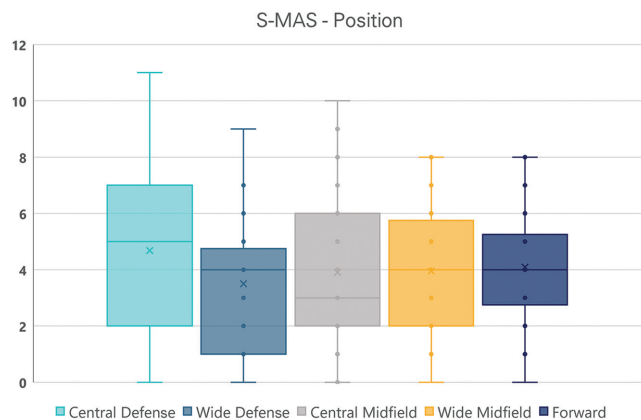
**Figure 3.** Intra- and interrater percentage agreement for individual Sprint Mechanics Assessment Score (S-MAS) parameters. CoM, center of mass. V, versus.

correlation coefficient (ICC) based on single measures using a 2-way mixed-effects model with absolute agreement with 95% CI in accordance with methods outlined by Koo and Li.<sup>25</sup> Standard error of measurement (SEM) was calculated as  $SD \cdot \sqrt{1 - ICC}$ . ICC values of  $<0.5$ , 0.5 to 0.75, 0.76 to 0.9, and  $>0.9$  were interpreted as poor, moderate, good, and excellent, respectively.<sup>25</sup> Reliability of individual items on the S-MAS was assessed using the Cohen kappa statistic and percentage agreements as described in previous literature.<sup>6</sup> Cohen kappa values were interpreted as follows:  $<0$ , poor; 0 to 0.20, slight; 0.21 to 0.40, fair; 0.41 to 0.60, moderate; 0.61 to 0.80, substantial; 0.81 to 1, almost perfect.<sup>27</sup> Percentage agreements were interpreted as follows:  $\leq 50\%$ , poor; 51% to 79%, moderate; and  $\geq 80\%$ , excellent.<sup>36</sup>

## RESULTS

ICC values for intrarater and interrater reliability showed good reliability with values of 0.828 (95% CI, 0.688-0.908) and 0.799 (95% CI, 0.642-0.892), respectively, with an SEM of 1 point. Based on kappa coefficients for individual items, 11 out of 12 parameters demonstrated moderate to substantial intrarater reliability, and 9 out of 12 demonstrated moderate to significant interrater reliability (Figure 2). Percentage agreements ranged from 75% to 88.8% for intrarater and 66.6% to 88.8% for interrater reliability, demonstrating moderate to excellent agreement for all parameters (Figure 3). For intertrial reliability, the mean S-MAS value for trial 1 was 4.1 (SD, 2.3) and for trial 2, 4 (SD, 2). The ICC was 0.74 (95% CI, 0.492-0.877), with an SEM of 1 point.

No significant differences were observed in S-MAS scores between male and female soccer players, 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 [SD, 2.7]) ( $P < .01$  [95% CI, 0.09-0.81]). No significant differences



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

were observed between playing position ( $P = .664$ ) (Figure 4). Using  $T$ -scores and benchmarking, S-MAS descriptors are presented in Figure 5.

## DISCUSSION

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

It is widely acknowledged that the interaction between multiple factors influences HSI development.<sup>3</sup> Eccentric hamstring strength, muscle architecture, 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.<sup>3,14,15</sup> In addition, biomechanical factors are believed to play a role in developing HSIs within team sports.<sup>14,22</sup> Although data from both prospective and retrospective investigations<sup>8,43</sup> support the associations between the two, research primarily utilizes 3D MoCap. This technology is undoubtedly 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 3D MoCap limits the ability to recruit large sample sizes in research studies and restricts the practical assessment of players in team sports settings. Addressing this limitation,

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

**Figure 5.** Normative benchmarking for S-MAS interpretation based on  $T$ -Scores. S-MAS, Sprint Mechanics Assessment Score.

the S-MAS offers a practical alternative to 3D MoCap by simply using the high-speed recording capabilities of a smart device, which is a common default feature of most tablet and smartphone technology, as well as free video-viewing software. Thus, it allows practitioners and coaches to quickly assess sprint running mechanics of players and teams, and identify those who may demonstrate kinematic patterns associated with HSIs.

Although some literature supports the association between isolated biomechanical parameters and HSIs, this relationship can often be conflicting.<sup>24,43</sup> Because muscle injuries occur as a result of the interaction between stress and strain,<sup>23</sup> it seems logical that a combination of mechanical patterns contributes to the occurrence of HSIs. This is reflected in multiple case reports where injury onset was associated with various mechanical features thought to influence overall tissue strain.<sup>18,41</sup>

The S-MAS utilizes a composite score that aims to reflect the collective contribution of multiple biomechanical parameters on potential HSI risk. This is similar to existing movement assessment tools such as the LESS<sup>38</sup> and CMAS<sup>10</sup> in relation to knee joint loads associated with anterior cruciate ligament 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 than the total score. In a previous study investigating the reliability of a qualitative analysis for endurance running, 5 parameters out of 15 demonstrated fair to poor interrater reliability,<sup>40</sup> indicating potential variations in the interpretation of isolated kinematic variables. In the present study, greater interrater reliability was observed; nonetheless, 3 parameters (back kick, trunk rotation, and trailing leg extension) still showed poor to fair interrater agreement based on kappa coefficients (see Figure 2). These parameters showed moderate percentage agreements (see Figure 3). Conversely, the overall S-MAS values demonstrate good inter- and intrarater reliability. This suggests that the overall score can be more confidently relied upon when identifying those 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 interpreting 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.<sup>29</sup> In contrast, other items represent altered lumbopelvic control and/or overstride mechanics. Identifying these subcomponents allows for developing specific, tailored movement interventions that have been proven capable of modifying movement patterns associated with HSIs.<sup>33,34</sup> Therefore, both the composite score and the individual items play complementary roles in using the S-MAS through identifying 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 data set to aid in the clinical interpretation of S-MAS values. This approach is commonly used for normative data benchmarking in sports performance and injury screening<sup>10,38</sup> and is similar to methods used for movement assessment scores, such as the LESS and CMAS. Based on the *T*-scores, S-MAS values of  $\leq 1$  were considered excellent, 2 as good, 3 to 5 as average, 6 as poor,  $\geq 7$  as very poor, and 12 as extremely poor. Across other movement assessment scores, Padua et al<sup>38</sup> used quartile ranges to separate scores on the LESS into severity categories, later reporting values  $>5$  (considered moderate to poor) to be associated with a greater incidence of future anterior cruciate ligament injuries.<sup>37</sup> Similarly, Dos’Santos et al<sup>10</sup> reported CMAS scores  $>7$  to be associated with greater knee joint loading parameters compared with scores of  $\leq 3$ . Therefore, using composite scores and normative ranges may aid the clinical interpretation of S-MAS values, assisting practitioners in identifying those who demonstrate potential higher-risk movement patterns and benefit from targeted gait interventions. However, it is important to be cautious with

this interpretation, as further work is required to establish the association between the S-MAS and HSIs.

Comparing results from the present study with those of previous authors, ICC values for the reliability of the S-MAS appear similar to other established movement assessment scores. The LESS score<sup>38</sup> has been shown to have ICC values of 0.910 and 0.840 for intra- and interrater reliability, while the CMAS<sup>10</sup> has shown ICC values of 0.946 and 0.690. This is similar to the present scores of 0.828 and 0.799 for intra- and interrater reliability. The good reliability of the S-MAS could be attributed to several factors. First, consistent with previous researchers, the 2 raters were provided with a training session before scoring videos and had a background in biomechanics.<sup>10,38</sup> It is unknown whether practitioner training improves reliability,<sup>26</sup> but it potentially allows for consistency in the application of the S-MAS and has been anecdotally suggested to improve interrater reliability.<sup>38,47</sup> Second, the S-MAS utilizes dichotomous ratings for individual items and clear definitions aiding the visualization of parameters. The use of dichotomous ratings has been shown to improve both within and between practitioner agreement in the visual assessment of movement patterns, removing ambiguity in identifying specific mechanical features.<sup>4,47</sup> Finally, the S-MAS utilizes predominantly sagittal plane movements, which are more pragmatic for data capture and allow easier screening against the established S-MAS criteria. Therefore, the combined use of practitioner training, along with clear assessment criteria and a dichotomous rating system, may contribute to the overall reliability of the S-MAS.

Even though no significant differences were observed between male and female soccer players, significant between-limb differences were found when comparing right and left limbs. However, the mean difference of 0.45 and 95% CI of 0.09 to 0.81 are less than the standard measurement error of the SEM of 1 point for the S-MAS. Therefore, the between-limb differences fall within the range that can be considered because of the intertrial variability of kinematic patterns. For future practical interpretation of differences in S-MAS scores, it is recommended to ensure that differences exceed the standard measurement error for differences to be considered potentially meaningful.

## LIMITATIONS

The present study has some limitations that need to be acknowledged. One is that there were only 2 raters, and both could be considered expert raters with  $>10$  years of experience in biomechanics and their respective professions. That said, the rater used for the intrarater reliability could be considered a novice user of the score. Although involved in the S-MAS development process, he had no experience utilizing the score before the reliability testing. Although a previous study by Whatman et al<sup>48</sup> suggested that more experienced raters demonstrate greater intra- and interrater reliability when visually scoring movement



compared with novices, these findings are equivocal. Several further studies have reported good to excellent intra- and intertester reliability among novices compared with experienced raters,<sup>7,17,46</sup> with 1 study utilizing the LESS (a composite score similar to the current work), reporting excellent intra- and intertester reliability of the LESS with ICCs of 0.835 among novice raters.<sup>36</sup> Therefore, we would hypothesize similar findings when comparing reliability of the S-MAS between larger groups of practitioners, particularly if training is conducted to standardize the use of the S-MAS score. However, we acknowledge that future work should consider evaluating the intertester reliability of the S-MAS between novice/inexperienced practitioners and practitioners of different professions (ie, sports scientists, physicians, coaches, etc).

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

Finally, the data presented in the present study pertain to those who were injury-free at the time of testing. Further work is required to investigate whether the S-MAS differs between those 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 that it can be easily integrated into practice to permit large mass screening of athletes from the community to the elite level. The presented normative benchmarking values may aid in the applied use of the S-MAS, facilitating the identification of those who demonstrate potential higher-risk sprint running mechanics and may benefit from interventions targeted toward optimizing movement quality.

## ORCID iDs

Christopher Bramah  <https://orcid.org/0000-0003-3644-9873>

Samantha Rhodes  <https://orcid.org/0000-0001-7121-1911>

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