Assessing Athletic Motor Skill Competencies in Youths: A Narrative Review of Movement Competency Screens

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ABSTRACT

Leading health organizations and long-term athletic development models have identified the need to develop movement competencies in children and adolescents. The athletic motor skill competencies (AMSCs) have been identified as key skills that form the foundations of all athletic movements. The AMSCs form an integral part of the long-term athletic development of youth, and improving these qualities should be central to coaches working with young individuals. Multiple movement competency screens assess some aspects of the AMSC spectrum, but there is no consensus regarding which screens may be most appropriate for a given cohort or coaching environment. This review provides an evaluation of the movement screens available to assess various AMSCs and in turn considers their reliability, feasibility, strengths, and weaknesses when used with youth populations.

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INTRODUCTION

Central to long-term athletic development models is the learning of movement skills in children and adolescents to allow for effective, efficient, and safe participation in physical activity and sports (53). Recognizing the need to develop a wide range of movement skills for athletic development, Lloyd et al. (32) proposed the athletic motor skill competencies (AMSCs) to help guide practitioners on the movement skills that need to be developed when working with youth athletes. The AMSCs incorporate the extensively researched fundamental movement skills (i.e., manipulative, locomotor, and stabilizing), but extends beyond these to include other motor skills that underpin more complex athletic performance in youth (32,35,69). Most athletic tasks and sport-specific skills will normally use multiple AMSCs to be performed competently (53). It can be considered that the AMSCs are essential developmental activities for all youth, and the acquisition of the AMSCs provides youth with the movement skills needed to navigate their environments. For instance, in physical activity during free play, children need the ability to produce and absorb force in the simple act of jumping and landing. Whereas in locomotor activities involved in physical activity and sport, youth athletes continually decelerate, change direction, and reaccelerate and thus require the ability to absorb and produce force both bilaterally and unilaterally in the lower limbs while controlling the core.

The AMSCs should be recognized as essential foundations to many movements observed in sport and physical activity to effectively engage in athletic development programs (53). For example, in the sport of badminton, players need to be able to frequently and

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effectively drop into the lunge position in continually evolving contexts. Developing the lunge movement, which is categorized as a lower-body unilateral movement within the AMSCs, provides youth with the skills needed to effectively execute positions required by the sport. Moreover, although the lunge is an important movement to many sporting contexts when prescribed under load, it is an effective exercise at enhancing muscular strength and proprioception (26). AMSC reflects the recent advancements in strength and conditioning research consolidating the efficacy of resistance training in youth; guiding practitioners on the movement skills that should be developed through long-term training programs (12,29,30).

For the long-term athletic development of youth, the need to be competent in a range of movements that underpin athleticism is widely accepted (31,32,53). The prepubertal years, synchronous with high levels of neuroplasticity, provide an opportune time to develop a wide range of movements (9,17,31,32). The development of the AMSCs should not, however, be exclusive to the prepubertal years, as many adolescents may not have been exposed to opportunities to develop such skills in their younger years. Practitioners working with youth populations should consider the development of AMSCs from 2 perspectives. Not only is the development of AMSC aimed to enhance children and adolescent's athleticism, allowing youth to reach their full athletic potential, but also for youth not engaged in sporting pathways. All children need to develop the physical skills required to navigate their ever-changing environments with confidence and competence and to create lifelong participation in physical activity (67,68).

Movement competency screens assess the qualitative aspects of movement, examining movement patterns and the ability to move well; therefore, they are deemed to be process-oriented assessments (64). Many previous studies investigating the effects of strength and conditioning on movement skills have typically implemented product-oriented assessments that measure outcomes of performance (i.e., distance jumped, sprint speed, and force produced) (5,64). Process-oriented assessments provide contextual information to movement deficits that may not be identified by product-oriented assessments in youth populations. Periodically assessing movement competency via process-oriented assessments to identify movement limitations and biomechanical deficits is important to enable practitioners the ability to design training programs that target the specific needs of each individual. For strength and conditioning practitioners and researchers to be able to measure AMSC, a movement screen that assesses the desired motor skills needs to be identified. Movement screens are often used by practitioners to assess athletic performance, injury risk, injury rehabilitation, and movement competency (3,16,18,34,37,42,48). Movement screening can be useful for practitioners by identifying strength, mobility, and neuromuscular deficits, subsequently guiding informed training prescriptions (16,43). As such, the use of movement screens in strength and conditioning has become common practice due to the contextual information that can be garnered on athletes (18,24,43,48,58,70,71). Movement screening can identify markers of injury risk in youth, with popular validated screens including the tuck jump assessment (TJA) (42), landing error scoring system (47), and drop jump assessments (55). Furthermore, to identify risk of injury, potential performance detriments, or talent identification purposes, sports-specific movement screens have been developed with notable contributions in golf (18) and netball (56). Previous research has demonstrated that youth do not possess good levels of movement competency, including those young athletes engaged in talent development programs (63,71). Therefore, to effectively engage in long-term athletic development models, young athletes need to focus on the development of AMSC.

Existing movement screens used in pediatric research, such as the test of gross motor development 2, have traditionally assessed fundamental movement skills (e.g., running, jumping, and throwing) (8,65). Yet, for practitioners aiming to develop athletic movements that underpin sport-specific skills in youth populations, a screen that goes beyond the traditionally defined fundamental movement skills is needed to assess the full array of AMSCs. Currently, there exists no universal movement screen that assesses all AMSCs; rather, multiple screens that assess one or several AMSCs exist. Therefore, the purpose of this review is to identify current movement screens and provide practical recommendations on which screens may best suit youth coaching environments to assess AMSC.

SEARCH STRATEGY

To examine current movement screens that incorporate AMSC, a Boolean search was conducted of Google Scholar and PubMed using the following search terms, "movement" or "movement competency" or "fundamental movement" or "athletic" or "athletic competency" or "screen." The search was to include English language studies published in peer-reviewed journals and movement screens incorporating exercises that are included in AMSC. Movement screens that primarily examined injury risk but satisfied the use of performance criteria (assessing the presence or absence of criteria needed to execute a skill (36)) rated by an administrator were included. Sport-specific screens and movement screens requiring 3D kinematic analysis were excluded. Fundamental movement skill screens based solely on investigating locomotor and manipulative skills not inclusive of AMSCs such as the test of gross motor development were also excluded. The test of gross motor development was developed to meet the need for a standardized test examining locomotor and object control skills in young children

Table 1
Summary of movement screens and AMSCs assessed

						AMSC included in the screen						
First author, y	Screen name	No. of skills	No. of criteria per skill	Scoring system per skill	Total score	Lower-body bilateral	Lower-body unilateral	Upper-body pushing	Upper-body pulling	Antirotation and core bracing	Jumping, landing, and rebounding mechanics	Tasks not included in the AMSC model
Cook, 2006a&b	FMS	7	3	0–3	21	Deep squat	Inline lunge | hurdle step	Trunk stability push-up		Rotary stability		Active straight leg raise | shoulder mobility
Myer, 2008	TJA	1	10	0–10	0–10						Tuck jump	
Lubans, 2014	RTSB	6	4–5	0 - 8 or 10	56	Body-weight squat	Lunge	Push-up | standing overhead press	Suspended row	Front support with chest touch		
Myer, 2014	BSA	1	10	0–10	10	Back squat						
Parsonage, 2014	CSMTs	6	3	0-3 or 1-4	20	Overhead squat | Romanian deadlift	Single-leg squat				Double-leg–single-leg landing | CMJ jump	
Bebich-Philip, 2016	RTSBc	6	4–5	0 - 8 or 10	56	Body-weight squat	Step-up	Push-up | overhead press	Suspended row	Chest touches		
Woods, 2016a	Modified AAA	5	3	1–3	63	Overhead squat	Double lunge | single-leg Romanian deadlift	Push-up	Chin-up			
Woods, 2016b	FGAMA	4	3	1–3	54	Overhead squat	Double lunge | single-leg Romanian deadlift	Push-up				
Fort-Vanmeerhaeghe, 2017	Modified TJA	1	10	0–20	0–20						Tuck jump	
Rogers, 2019	AIMS	4	4	1–3	48	Overhead squat	Lunge	Push-up		Front support brace and chest touch		

AAA = athletic ability assessment; AIMS = athlete introductory movement screen; AMSC = athletic motor skill competencies; BSA = back squat assessment; CMJ = countermovement jump; CSMTs = conditioning-specific movement tasks; FGAMA = fundamental gross athletic movement assessment; FMS = functional movement screen; MCS = movement competence screen assessment; RTSB = resistance training skill battery; RTSBc = resistance training skill battery for children; TJA = tuck jump.

(65). However, the test is devoid of AMSC, and Rudd et al. (61) highlighted the need for stabilizing skills in fundamental movement skill assessments.

In total, 10 movement screens were deemed appropriate for this review. Table 1 provides a summary of the exercises included within each screen. AMSCs comprise 8 categories; however, for this review, the throwing, catching, and grasping category has not been included in Table 1. The throwing, catching, and grasping category includes movements that are predominantly fundamental movement skills and assessed by the test of gross motor development. Except for the notable exception of Parsonage et al. (48), none of the movement screens assess acceleration, deceleration, and reacceleration competency; therefore, despite its importance for athletic development, this category was not included in Table 1. The movement screens featured in Table 1 include between 1 and 5 AMSC categories.

MOVEMENT SCREEN RELIABILITY

For each screen identified, a further search was conducted using the term "reliability" and the title of each screen, with only studies on youth populations (>18 years old) included in this review. The reliability of each screen and sample populations are summarized in Table 2. To be included in this part of the review, the movement screens were examined to determine whether rater-reliability statistics had been reported in a youth population. Reliability, a measure of consistency, is frequently quantified in movement science literature using the intraclass correlation coefficient (ICC) (66) and kappa statistic (62) for both intra- (within) and inter- (between) rater reliability. Previous studies implementing the intraclass correlation coefficient to determine rater reliability have used the following categorizations: 0.00–0.69 poor reliability, 0.70–0.79 fair reliability, 0.80–0.89 good reliability, and 0.9–0.99 high relative reliability (37,58). For the kappa statistic, previous research has interpreted the following: 0.21–0.4 fair agreement, 0.41–0.6 moderate agreement, 0.61–0.80 substantial agreement, and 0.81–1.00 almost perfect agreement (28,58,62). As shown in Table 2, reliability statistics were available for all movement screens initially identified.

In Table 2, the intraclass correlation coefficients have been applied to the total scores of an entire screen or the total scores across a number of criteria in a given movement. All studies report good or excellent reliability of total scores based on intraclass correlation coefficient. Kappa scores have been calculated based on the consistency of rating of each performance criteria with reliability ranging from fair to good. In an applied sense, this means that practitioners can have confidence in using total scores, and although a little more caution is needed when interpreting a single criterion, those criteria are also typically deemed to be reliable. Practitioners considering the use of multiple raters to perform screening should consider screens that report interrater reliability. However, for good practice when using a screen across multiple raters with no prior demonstration of interrater reliability, then interrater should first be established for each individual rater. Similarly, in the case of an individual rater, practitioners should still determine their intrarater reliability to ensure that they can produce consistent and reliable scoring. All individual movements from movement screens with demonstrated reliability in youth populations are shown in Figure 1.

Implementing movement competency screens can assist practitioners in understanding whether growth and maturation are leading to any improvement or disruption to AMSCs or whether a training intervention has been successful at improving movement patterns. To enable practitioners to decipher whether observed changes in movement patterns are real, practitioners need to be aware of the potential level of human variability that exists when grading movement competencies. The typical error quantifies the level of random variability expected within a screen and has been reported for both the resistance training skills battery (RTSB) (TE = 2.5) and the AIMS (TE = 0.9–1.8) (36,58). Where changes in AMSC over time are greater than the typical error, practitioners can have confidence that these represent meaningful changes. Practitioners are advised to use screens where the level of typical error has already been quantified or to establish the level of error using repeated ratings of their data.

IMPLEMENTING MOVEMENT SCREENS

Although many movement screens exist in the literature, there is a lack of consistency in terms of best practices on how to implement screens, grade criteria, and analyze movements. Recommendations on who should implement screens (i.e., teachers, strength coaches, and physical therapists) are limited. However, research has demonstrated that when comparing both novice and expert raters' substantial agreement in reliability can still be achieved (38). To assist with movement screen rating, it is recommended that practitioners record movements to be analyzed retrospectively post-testing, alleviating the pressures of recalling the grading criteria in real time. Practitioners can pause, slow down, and rewatch footage when rating retrospectively, allowing as much time as required to decipher a score, a technique recommended to raters by Rogers et al. (58).

When screening youth populations, one key factor to consider is the number of repetitions that are performed and whether repetitions are graded individually or combined. Considering the maturation of the brain in youth, areas involved with the execution of motor co-ordination (frontal lobes) are still maturing from birth to adulthood (17); consequently, children and adolescents experience higher levels of movement variability. In addition, regressions in performance can occur in line with the adolescent growth spurt (19); therefore, development of

AMSC should be considered nonlinear in youth. As such, movement screens should consider movement variability and look to assess each repetition across multiple repetitions to evaluate movement consistency. The functional movement screen (FMS), RTSB, conditioning-specific movement task (CSMT), and RTSB (children) adopt a best repetition technique for scoring (2,6,7,36,48), whereby practitioners select the repetition deemed to reflect best performance, which is then graded accordingly. Such an approach may limit a movement screen's ability to assess the AMSC across multiple repetitions and therefore lack indication of a young person's ability to perform AMSC with consistency. The TJA, back squat assessment (BSA), modified athletic ability assessment (AAA), fundamental gross athletic movement assessment (FGAMA), and modified TJA use a sum of repetition scoring system that begins to recognize inconsistency in movement considerations (15,42,43,70,71). This approach may leave some ambiguity when grading as practitioners have to decipher where to score an individual on what they perceived to be the average level of movement across multiple repetitions. Scoring across multiple repetitions with grading corresponding to the number of appropriate repetitions performed as seen in the athlete introductory movement screen (AIMS) may be best equipped to investigate movement competency that considers variability (58). Another important factor to consider when deciding which movement screen may be used to assess AMSC is whether a screen uses a whole-body or segmental analysis. Screens that use a whole-body approach (e.g., FMS) may fail to indicate where specific movement deficiencies or compensations occur, information that is required to inform and individualize training. The segmental analysis scores different body parts during a movement and provides more detail to identify where and why movement competency is limited. The segmental approach will subsequently allow practitioners to tailor training programs to the need of each young athlete. For each screen included in this review, the assessment techniques adopted by the screens are included in Table 3.

ANALYSIS OF AVAILABLE MOVEMENT SCREENS

FUNCTIONAL MOVEMENT SCREEN

The FMS comprises 7 movements that include 4 of the AMSC model categories (lower-body bilateral, lower-body unilateral, upper-body pushing, antirotation, and core bracing). Cook et al. (6,7) presented the FMS as a preparticipation screen to determine an individual's ability to perform movements deemed essential for participation in sport. In addition, the authors identified movement deficiencies previously seen as significant risk factors that can be identified by the screen (7). However, subsequent research has since identified this screen to be a poor predictor of injury (1,23,44).

The FMS screen scores each exercise from 0 to 3 and if a participant scores a 3 on the first repetition, no more repetitions are performed on that movement. This technique may indicate where a participant is competent in a select movement but may not show if an athlete can perform that movement consistently if they score perfectly on the first repetition.

The approach used by the FMS may not examine a youth's ability to perform a movement consistently, which is essential when assessing AMSC. The FMS implements a whole-body analysis, whereby the grading of performance criteria is not directly aligned to specific segments, and often, further screening is required to establish the origin of the movement dysfunction.

Despite its potential limitations, research exists demonstrating the efficacy of the FMS to be used in youth contexts (34,40). The FMS has demonstrated associations with performance tests such as the squat jump, maximal hopping protocol, and reactive agility cut in youth soccer players (34). Such associations suggest that the screen might be useful for practitioners to use to identify limitations in movement competency that impact physical performance. A recent review investigating strategies to enhancing movement competency in youth athletes identified the FMS to be the most commonly used assessment (59) Studies included in the review consisted of between 1 and 4 sessions weekly over a 4–16-week period, varying from 10-minute warm-ups to 60-minute gym sessions focusing on movement competency and/or strength training. Of the 5 reported studies using the FMS in the review by Rogers et al. (59), 4 studies demonstrated changes in movement competency. The authors' findings further consolidate the effectiveness of targeting movement competency through interventions. Practitioners should use the FMS with caution due to its contrasting findings surrounding its link to injury risk. Furthermore, the FMS scoring system and need for equipment make the screen less suitable to use with youth populations and in large cohorts.

TUCK JUMP ASSESSMENT

Initially created as an assessment tool to identify biomechanical deficits associated with anterior cruciate ligament injury (ACL) risk (42), the TJA assesses one of the AMSCs (i.e., jumping, landing, and rebounding mechanics). The TJA assesses 10 movement deficits over multiple repetitions, providing practitioners with detail on an individual's ability to maintain orientation while jumping, to produce and absorb force, and their potential risk of injury (42). Individuals score between 0 and 10 on the TJA, with a score of 1 noted for each deficit identified and a lower total score indicative of better competency. The 10 movement deficits cover 3 key areas: knee and thigh motion, foot position during landing, and plyometric technique. Each of the performance criteria is examined retrospectively from both video footage of the frontal and sagittal planes of view.

Other notable movement screens that have been developed similar to the TJA are the drop vertical jump assessment (21) and the landing error scoring system (47). Both have provided notable research contributions and, similar to the tuck jump, have been created as

Table 2
Intraclass correlation coefficient (confidence interval) and kappa reliability statistics for movement screens that assess AMSC

Screen title	Author, y	Population characteristics	Participants no. (age, y)	Reliability (confidence interval)
FMS	Parenteau-G et al., 2014	Male ice hockey players	30 (13–17 y)	ICC inter = 0.96 (0.92–0.98) ICC intra = 0.96 (0.92–0.98)
	Wright et al., 2015	Secondary school students	22 (13.4 ± 0.9 y)	Kappa inter = 0.11–0.83 Kappa intra = 0.23–0.87
TJA	Read et al., 2016	Male youth soccer players	25 pre-PHV (11.93 ± 0.43 y) 25 post-PHV (17.26 ± 0.69 y)	ICC intra = 0.88
	Pullen et al., 2020	Secondary school students	10 (11–14 y)	ICC intra = 0.91 Kappa intra = 0.29–1.00
RTSB	Lubans et al., 2014	Secondary school students	63 (14.5 ± 1.1 y)	ICC inter = 0.88 (0.80–0.93)
	Pichardo et al., 2019	Secondary school students	10 circa-PHV (13–14 y)	ICC intra = 0.96
	Pullen et al., 2020	Secondary school students	10 (11–14 y)	ICC intra = 0.97 Kappa intra = 0.36–0.61
BSA	Dobbs et al., 2019	Elite youth male cricketers	26 (pre-PHV) <12 y 22 (post-PHV) < 17 y	ICC intra = 0.98 (0.96–1.00) ICC intra = 0.97 (0.95–1.00)
CSMTs	Parsonage et al., 2014	Male rugby players	156 (15 ± 0.7 y)	Kappa inter = 0.62–1.00 Kappa intra = 0.61–1.00
RTSBc	Bebich-Philip et al., 2016	Children from the community	20 (8.2 ± 1.2 y)	ICC intra = 0.97 (0.94–0.98)
Modified AAA	Woods et al., 2016a	Elite junior Australian football players	22 (17.8 ± 0.7 y)	Kappa intra = 0.59–0.75
FGAMA	Woods et al., 2016b	Talent- and non–talent-identified Australian football players	25 (17.7 ± 0.4 y) & 25 (17.5 ± 0.6 y)	Kappa intra = 0.71–0.91
Modified TJA	Fort-Vanmeerhaeghe et al., 2017	Elite youth volleyball athletes	24 (15.79 ± 0.63)	ICC inter = 0.94 (0.88–0.97) ICC intra 1 = 0.94 (0.88–0.97) ICC intra 2 = 0.96 (0.92–0.98)
AIMS	Rogers et al., 2019	Male and female junior athletes	28 (15.7 ± 1.8 y)	ICC inter = 0.88 (0.76–0.94) ICC intra = 0.97 (0.94–0.99)

AAA = athletic ability assessment; AIMS = athlete introductory movement screen; AMSC = athletic motor skill competencies; BSA = back squat assessment; CSMTs = conditioning-specific movement tasks; FGAMA = fundamental gross athletic movement assessment; FMS = functional movement screen; ICC = intraclass correlation coefficient; inter = interrater; intra = intrarater; PHV = peak height velocity; RTSB = resistance training skills battery; RTSBc = resistance training skills battery for children; TJA = tuck jump assessment.

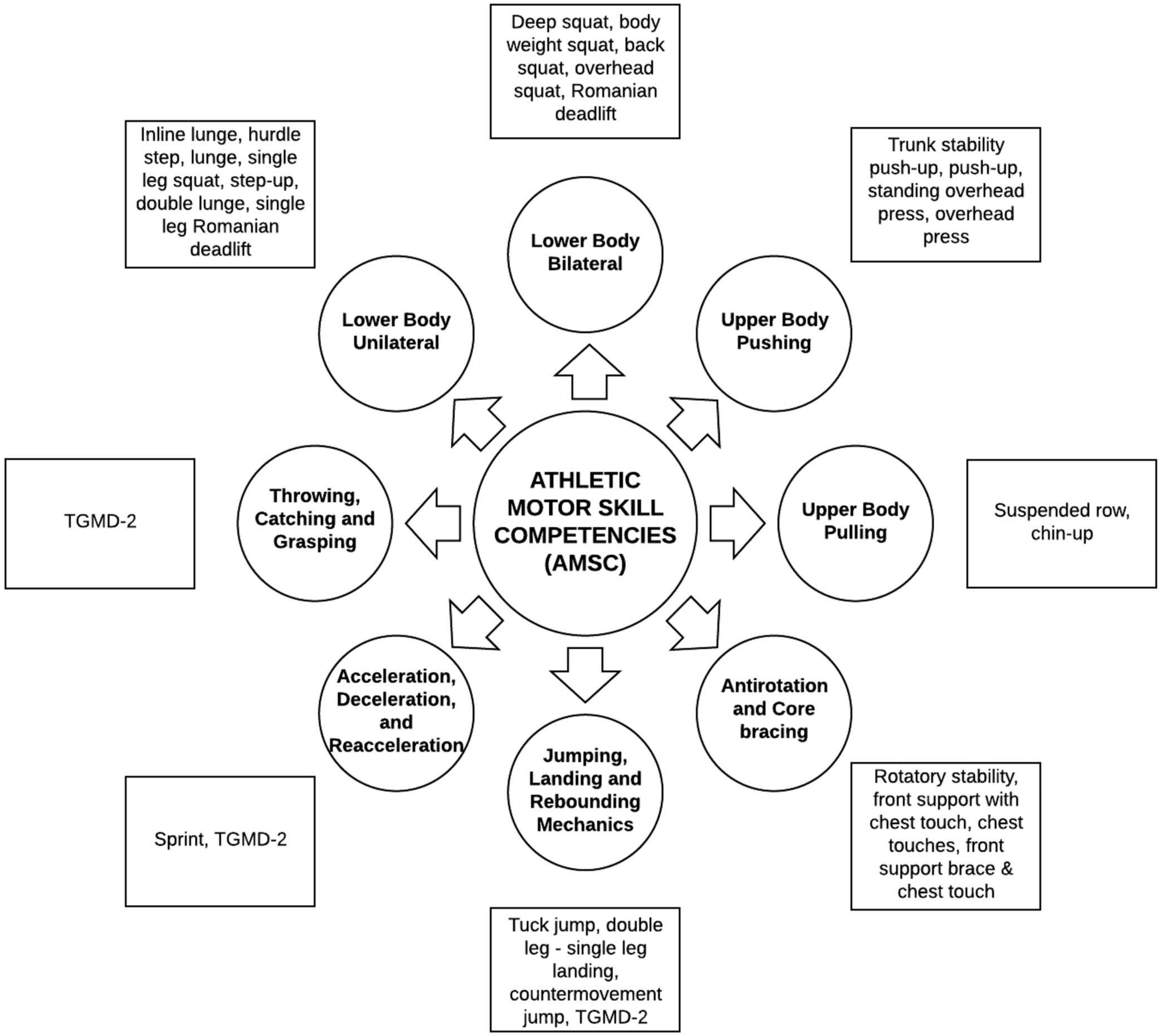

Figure 1. Athletic motor skill competencies and the associated movement screen exercises. Adapted from: Strength and Conditioning for Young Athletes, 2nd Edition by RS Lloyd and JL Oliver, Copyright 2019 by Routledge. Reproduced by permission of Taylor & Francis Group.

a screen to investigate lower limb injury risk factors. To assess biomechanical deficits, the drop vertical jump test uses 3D motion capture that will not be accessible to most practitioners. Noyes et al. (45) successfully used 2D video capture to assess biomechanical deficits using the drop vertical test; however, research has indicated that the TJA is a more suitable screen for identifying frontal plane projection angles than the drop jump (33). Furthermore, the TJA is more sensitive to between-maturity group differences than the drop jump in a youth population of male soccer players (33). Sensitivity of the TJA to assess differences in stages of maturation is further supported by Read et al. (54), who revealed that knee valgus scores were lower in postpeak height velocity compared with prepeak height velocity male youth soccer players, and noteworthy interlimb asymmetries were evident in circa-peak height velocity boys (54). Peak height velocity represents the age at which the maximum rate of growth coincides with the adolescent growth spurt (39). Because of the multiple repetitions within the protocol, the TJA may be better able to identify movement deficiencies caused by adolescent awkwardness, which reflects the temporary regression in sensorimotor function experienced by some adolescents (52).

Table 3
Scoring techniques used by different movement screens that assess AMSC

Screen title	No. of sets and repetitions performed	Whole-body or segmental analysis	Assessing technique	Repetition consistency scoring	Segmental criteria scoring
FMS	1 × 1–3	Whole body	Best repetition technique	n/a	Pass or fail
TJA	1 × 10 s	Segmental	Sum of repetitions scoring	Inconsistency considerations	Pass or fail
RTSB	2 × 4	Segmental	Best repetition technique per each set	n/a	Pass or fail
BSA	1 × 10	Segmental	Sum of repetitions scoring	Inconsistency considerations	Pass or fail
CSMTs	1 × 1	Whole body	Best repetition technique	n/a	3–1
RTSBc	2 × 4	Segmental	Best repetition technique per each set	n/a	Pass or fail
Modified AAA	1 × 5/10/30	Segmental	Sum of repetitions scoring	Inconsistency considerations	3–1
FGAMA	1 × 5/30	Segmental	Sum of repetitions scoring	Inconsistency considerations	3–1
Modified TJA	1 × 10 s	Segmental	Sum of repetitions scoring	Inconsistency considerations	0–2
AIMS	2 × 4	Segmental	Sum of repetitions scoring	Scored on number of appropriate repetitions	3–1

AAA = athletic ability assessment; AIMS = athlete introductory movement screen; AMSC = athletic motor skill competencies; BSA = back squat assessment; CSMTs = conditioning-specific movement tasks; FGAMA = fundamental gross athletic movement assessment; FMS = functional movement screen; RTSB = resistance training skills battery; RTSBc = resistance training skills battery for children; s = seconds; TJA = tuck jump assessment.

Over recent years, a body of research has demonstrated support for the use of the TJA with young athletes. Oliver et al. (46), using machine learning, attributed tuck jump knee valgus to be a contributing factor to an injurious profile in youth football players. In female athletes, knee motion and knee loading during the tuck jump task have also been shown to be a predictor of ACL injury risk (20). Furthermore, the TJA has been used to demonstrate the efficacy of implementing a combination of resistance and plyometric training together to enhance performance (49).

The TJA has been modified to provide additional risk factor categorization for each of the performance criteria scored. Myer et al. (41) grouped modifiable risk factors into the following: ligament dominance, quadriceps dominance, leg dominance or residual injury deficits, trunk dominance (core dysfunction), and technique perfection. Such categorization allows practitioners to implement strength and conditioning training aimed at correcting the identified risk factors. The development of a modified TJA has strengthened the use of the screen to become more sensitive to detecting changes in movement competency (15). The modified TJA uses the same movement criteria but extends scoring from a simple pass/fail score or 0 or 1 to a score of 0, 1, or 2 to identify a pass or the magnitude of how the criterion has not met standard. The modified version therefore scores individuals between 0 and 20, and as such, it may be more sensitive to change than its predecessor, as the original dichotomous scoring system of the TJA does not evaluate the severity of dysfunction within each item (15). The modified TJA has exhibited sex and maturation interactions; females demonstrate greater knee valgus and more fatigue compared with males, with increases in knee valgus at landing with each stage of maturation (14). In summary, the TJA's ability to identify injury risk factors, fast application, minimal testing equipment, and comprehensive scoring system makes it a valuable screen to use in youth in multiple contexts.

THE RESISTANCE TRAINING SKILL BATTERY

The RTSB is the only movement screen included in this review that is specifically designed for use in a school setting (36). Comprised of 6 movements, including 5 of the AMSC categories (lower-body bilateral, lower-body unilateral, upper-body pushing, upper-body pulling, antirotation, and core bracing), the screen requires minimal equipment (a wooden bar and an anchor point for suspension straps) and is time efficient. The RTSB scores participants out of 8 or 10 points per movement, and a total score of 56 can be attained.

The RTSB implements a segmental analysis to assessing movement competency. For each movement, there are 4 or 5 performance criteria associated with specific segments of the body, which participants can either score a "pass" or "fail" for each criterion. Accordingly, practitioners who use the RTSB segmental analyses can effectively identify movement deficiencies and prescribe corrective exercises. A limitation of the RTSB is that only the best repetition of 4 is rated; however, this is repeated over 2 sets, thus providing some consideration of consistency of movement.

In a recent study on school children, the RTSB demonstrated a positive relationship with physical fitness, whereby children scoring higher in the RTSB demonstrated higher levels of physical fitness (36). Therefore, it could be considered that increasing competency in the RTSB has the potential to transfer benefits to physical fitness. In addition, findings from Smith et al. (63) supported a strong link between muscular fitness and RTSB score in school-based adolescents. Similarly, Pichardo et al. (50) demonstrated that the RTSB was associated with isometric midthigh pull peak force in adolescent boys; specifically, boys with low strength (Z score > - 1.0 in isometric midthigh pull) were nearly 8 times more likely to score poorly in the RTSB (i.e., low competency) compared with boys who had high levels of strength. Accordingly, due to the associations with isometric peak force, practitioners should consider assessing strength as well as competency to identify whether a young person's limitations exist due to the inability to navigate one's body in space or the inability to produce force. The need to assess muscular strength alongside movement competency has been supported by Cattuzzo et al. (4) who propose the need to view strength and coordination in synergy rather than separate entities.

Strength and conditioning interventions based in school environments have demonstrated the ability to enhance AMSC via improvements in movements included in the RTSB (49,51). Pullen et al. (51) delivered an intervention aimed at improving AMSC in secondary school children in years 7–9 (11–14 years old). The lead author incorporated a constraints-led approach (57) into games, challenges, and movement exploration. The authors revealed that the RTSB was sensitive enough to detect changes in AMSC in an intervention totaling nine, 40-minute sessions over a 7-week duration. Significant improvements in total RTSB score occurred, and movements such as the squat, lunge, and front support brace with shoulder tap significantly improved. No changes occurred in standing long jump performance, suggesting that improvements in movement competency may emerge before changes in physical performance, which are also supported by the research of Moeskops et al. (40).

Bebich-Philip et al. (2) adapted the RTSB to be used with 6–12-year-old children and reported very good interrater and intrarater reliability. The authors of the modified RTSB consulted with the authors of the original RTSB and consequently; the lunge was replaced with the step-up to decrease the balance difficulty while maintaining a dynamic lower limb movement in the screen (2). In summary, the literature indicates that the RTSB requires minimal equipment, is reliable, measures numerous AMSCs, is related to physical fitness, and seems to be sensitive to detect changes in movement competency following training (2,36,50,63). Consequently, the RTSB is considered a good option for practitioners wanting to measure AMSC in young populations.

BACK SQUAT ASSESSMENT

Established as a fundamental movement for strength training (25), all movement screens identified in Table 1 are inclusive of a squat variation, which is a common variant of lower-body bilateral movements within the AMSC spectrum. The BSA provides information concerning an athlete's ankle mobility, knee stability, hip mobility, lumbar stability, thoracic mobility, and head positioning while interpreting movement limitations due to neuromuscular, strength, or mobility limitations (25). Of the 5 movement screens that have demonstrated the reliability of the squat in youth populations, the BSA (43) seems to be the most comprehensive.

It is recommended that the BSA be filmed in anterior, posterior, and lateral views and graded retrospectively (43). Similar to the TJA, the BSA implements a negative scoring system with 10 movement criteria rated across 10 repetitions of the squat. The BSA splits movement criteria across 3 domains; the upper body, lower body, and movement mechanics. The BSA grading criteria, unlike the FMS or RTSB, consider a young person's movement across multiple repetitions, and a deficit is marked if an athlete fails to demonstrate technical proficiency for a criterion for 2 or more repetitions (43).

Dobbs et al. (11) used the BSA to assess changes in movement competency after a 4-week intervention, revealing the screen to be sensitive to detect competency improvements in both pre- and post-peak height velocity athletes. However, a more recent study suggested that a strength and conditioning intervention was not effective at improving BSA (10), although the intervention had a primary focus on increasing strength and not movement competency. Accordingly, to improve movement competency, interventions may need to focus on strategies that promote the acquisition of new skills, not just the enhancement of muscular strength. Moreover, the findings from the study could further add to the need to use multiple movements or to offer progressions to the BSA, such as performing the screen under an external load. Using multiple movement skills could make a movement screen protocol more sensitive to identifying changes in movement competency.

Although the BSA provides a detailed scoring system, when used in isolation, the screen is limited to assessing just one of the AMSC's and will not provide a holistic evaluation of competency across a range of movements. The BSA does not consider lower limb unilateral or core bracing and antirotation exercises that examine integration of unilateral hip stability, and the ability to maintain trunk integrity, as seen in other screens (26,36). Notwithstanding potential limitations, the BSA requires minimal testing equipment and could be implemented with large cohorts. One of the strengths of the BSA is the accompanying information provided by the authors, providing detailed analysis of individual criteria of each subdomain alongside a range of exercises and progressions to target each movement deficit (27,43). Desired technique and common deficits linked to neuromuscular strength, stability, and mobility limitations are provided for all upper-body (head position, thoracic position, and trunk position), lower-body (hip position, frontal knee position, tibial progression angle, and foot position), and movement mechanics (descent, depth, and ascent) criteria. The BSA and accompanying information guides practitioners to identifying and targeting corrections for biomechanical deficits (43). When using other movement screens that include squat movements, the BSA can be used to provide deeper understanding of the potential deficits being exhibited by youth athletes.

CONDITIONING-SPECIFIC MOVEMENT TASKS

The CSMTs are the only movement screen to include an exercise that is incorporated in the acceleration, deceleration, and reacceleration components of the AMSC model via the sprint. The CSMT also includes 3 other categories from the model (lower-body bilateral, lower-body unilateral, jumping, landing, and rebounding mechanics). The screen was designed to identify strength and conditioning–related movement competency within talented academy rugby players and demonstrated acceptable reliability (k = 0.61–1.00) in an adolescent population (48).

Participants are instructed to perform 2 repetitions of all 6 different movements (overhead squat, Romanian deadlift, single-leg squat, double- and single-leg landing, sprint, and countermovement jump), which are filmed in both the frontal and sagittal planes and retrospectively graded. The CMST implements whole-body analysis, and therefore, practitioners may not benefit from the aforementioned qualities associated with segmental analysis. The CMST adopts a similar 4-point scale to the FMS, whereby 0 is awarded in the presence of pain, 1 if unable to complete the movement correctly, 2 in the presence of compensatory movements, and 3 for correct movement (48). Using the best repetition technique to assessing competency, a total score of 20 can be attained in the CMST.

A study by Parsonage et al. (48) demonstrated that in an athletic rugby academy environment, movement competency of adolescents was low. For example, the proportion of competent (scoring 2 or above) players was reported to be as low as 14% for single-leg squat movements. Furthermore, the authors examined fitness test scores between competency groups. The low competency score group had significantly lower jump height, slower sprint speeds, and covered less distance in the Yo-Yo intermittent test (48). Such findings are in line with other research that identifies associations between strength and competency in young athletes (36,50). These observations highlight the need to concurrently use assessments of force production alongside movement competency screens to understand whether low competency might be the result of low levels of strength or poor movement control. The use of the CMST by Parsonage et al. (48) demonstrates that practitioners should not assume that youth athletes have good movement competency.

ATHLETIC ABILITY ASSESSMENT

Initially introduced by McKeown et al. (37), the Athletic Ability Assessment, AAA, was created to assess movement ability in athletes alongside performance and physical fitness characteristics. The authors' desire to create the AAA stemmed from the identification that the FMS was most commonly used to assess movement competency, yet its validity was limited within athletic populations (25,71). Subsequently, the AAA was designed to investigate athletic movements determined by the authors to be commonplace in strength and conditioning training (37). To the authors' knowledge, no studies exist examining the reliability of the AAA in youth populations. However, since the creation of the AAA, 2 modified versions of the screen have emerged. First, the modified AAA was introduced by Wood et al. (71) as a means to compare athletic movement competency between senior and junior Australian football players. The second modified version, called the FGAMA, was created to be able to discriminate between talent- and non–talent-identified athletes' movement competency (70). Both the modified AAA (k = 0.59–0.75) and FGAMA (k = 0.71–0.91) have demonstrated reliability in youth populations.

The modified AAA comprises 5 exercises that incorporate 4 AMSC categories (lower-body bilateral, lower-body unilateral, upper-body pushing, and upper-body pushing). The screen implements a segmental analysis with a 3-point scale across 3 assessment points per exercise. Therefore, a total of 9 points per movement is attainable, and a total score of 63 points can be achieved for the entire screen (due to some movements being scored twice in the case of unilateral movements). Some of the assessment points consider movement variability by offering the opportunity to deduct points for inconsistent movement (push-up and chin-up), but this is not applied universally across all movements. The study by Woods et al. (71) demonstrated that the screen could differentiate competency levels in athletic motor skills between junior and senior athletes in an Australian Football League club.

The FGAMA is a continuation of the AAA and modified AAA. Designed for use in a youth population, the screen was created to determine whether athletic movement skills are discriminant qualities in junior Australian football players (70). Woods et al. (70) recognized some potential limitations of the modified AAA, namely that the modified AAA was monodimensional, characterized by measures of competency that are underpinned by physical fitness or anthropometrics (22,70). Consequently, the pull-up movement, underpinned by the need to produce high levels of muscular force in the upper body, was removed. The FGAMA comprises 4 exercises incorporating 3 AMSC categories (lower-body bilateral, lower-body unilateral, and upper-body push). Using similar performance criteria to the modified AAA, the screen scores up to 3 points for 3 key performance criteria of each movement, and thus, a total of 9 points can be attained for each movement, with a maximum of 54 points available for the whole screen (accounting for unilateral movements being scored individually for each limb). The screen recognizes the need to investigate movement variability; however, it only scores for inconsistencies in the push-up movement.

The screen has previously been used as a means to differentiate movement capabilities of academy (talent identified) and nonacademy (non–talent identified) junior Australian football players (70). Woods et al. (70) concluded that talent-identified athletes scored higher in the movement screen, particularly in the overhead squat movement.

Both the modified AAA and FGAMA demonstrate the ability to distinguish between different athletic populations. When working with nonathletic youth populations, the FGAMA is recommended due to the screen being more process oriented in nature and therefore may be more suitable to use with younger or less trained populations. Practitioners can therefore identify which version of the AAA best fits the needs of the population and the environment they are working in.

ATHLETE INTRODUCTORY MOVEMENT SCREEN

The AIMS is the most recent screen to emerge in the scientific literature, consisting of 4 exercises, incorporating 4 AMSC categories (lower-body bilateral, lower-body unilateral, upper-body push, and antirotation and core bracing). Rogers et al. (58) developed the AIMS to provide a novel movement screen for youth sport practitioners. The authors aimed to retain the strengths of the RTSB while addressing the shortcomings of the FMS that were adopted by AAA (36,58). To that end, the AIMS adapts the performance criteria from the AAA and adopts movements from the RTSB (36). The authors recognized that some of the movements require equipment standardization across multiple testing environments, thus increasing the time required to complete the screen. Consequently, the suspended row and overhead press movements were removed. In addition, the bodyweight squat movement has subsequently been changed to an overhead squat in line with the AAA, providing more information pertaining to an individual's shoulder mobility, neuromuscular control, and integrated stability of the trunk (58).

The AIMS is the only movement screen included in this review that explicitly outlines a performance criterion scoring system that scores all criteria across multiple repetitions and offers an exact score based on the number of correct repetitions performed. Scoring across a number of body segments, the screen captures performance in movements from both the frontal and sagittal view (58). For example, for the overhead squat movement, the criteria for the heels are assessed from the sagittal view to score 3 points = heels remain on the floor for all 4 repetitions, 2 points = 3 appropriate repetitions, and 1 point = 2 or less appropriate repetitions. This system is scaled for all 4 of the individual movement criteria for all 4 exercises in the movement screen. In some instances, the screen also attempts to account for some variation in technique. For example, for hand position in the push-up, 2 points = minor mispositioning or 1 repositioning of hands and 1 point = poor initial positioning or 2 repositioning of hands. Scoring across multiple repetitions in this way means that the AIMS provides the greatest consideration of consistency and variability of movement across the screens included in this review.

Each movement included in the AIMS comprises 4 performance criteria, with each criterion scored between 1 and 4. Therefore, the total score for each exercise ranges from 4 to 12, and the total score for the screen ranges from 16 to 48. In a study of 28 junior athletes, Rodgers et al. (58) examined the 4 movements incorporated in the AIMS, for overhead squat, lunge, and brace with chest touch, youth athletes most frequently scored 8 out of the potential 12 points; whereas for the push-up movement, the participants scored 11 most frequently. In the youth athlete cohort, it should be noted that some athletes still scored the minimum score of 4 points in the overhead squat. Accordingly, in line with previous findings from research using the CSMT and the modified AAA, movement competency is not fully developed even in athletic youth populations, and technique in AMSC should be continually targeted into adulthood. In another study, Rogers et al. (60) used the AIMS to investigate the effectiveness of an online movement competency intervention versus a face-to-face coached intervention. The participants, volunteers recruited from a local high school, demonstrated the lowest levels of competency in the overhead squat movement (60).

The AIMS incorporates many AMSC categories and has built on the strengths of the AAA and RTSB to create a movement screen that considers movement consistency across multiple repetitions. The techniques used in the screen provide practitioners with in-depth information pertaining to youth

Table 4
Movement competency screen decision table for strength and conditioning coaches

Screen title	Number of AMSC categories	Level of reliability for total of all movements (ICC)	Scoring techniques				Example intervention studies in youth	Intervention population
			Segmental	Sum of repetitions	Consistency consideration	3-Point segmental criteria scoring		
FMS	4	Inter = 0.96 Intra = 0.96	×	×	×	×	Wright et al. (2015) Moeskops et al. (2018)	Gifted and talented local secondary school children Female artistic gymnasts
TJA	1	Intra = 0.88 Intra = 0.91	✓	✓	✓	×	Pichardo et al. (2019) Pullen et al. (2020)	Male secondary school children Secondary school children
RTSB	5	Inter = 0.88 Intra = 0.91	✓	×	×	×	Pichardo et al. (2019) Pullen et al. (2020)	Male secondary school children Secondary school children
BSA	1	Intra = 0.98 Intra = 0.97	✓	✓	✓	×	Dobbs et al. (2019) Dobbs et al. (2020)	Elite youth male cricketers Elite youth male cricketers
CSMTs	3	N/A	×	×	×	✓		
RTSBc	5	Intra = 0.97	✓	×	×	×		
Modified AAA	4	N/A	✓	✓	✓	✓		
FGAMA	3	N/A	✓	✓	✓	✓		
Modified TJA	1	Inter = 0.94 Intra = 0.94 & 0.96	✓	✓	✓	✓		
AIMS	4	Inter = 0.88 Intra = 0.97	✓	✓	✓✓	✓	Rogers et al. (2020)	Male and female junior athletes

AAA = athletic ability assessment; AIMS = athlete introductory movement screen; AMSC = athletic motor skill competencies; BSA = back squat assessment; CSMTs = conditioning-specific movement tasks; FGAMA = fundamental gross athletic movement assessment; FMS = functional movement screen; RTSB = resistance training skills battery; RTSBc = resistance training skills battery for children; s = seconds; TJA = tuck jump assessment.

Table 5 Example movement competency screening batteries					
Option	Screens and strength measures included	Appropriate testing environment	Number of AMSC categories	Skills in each battery	Strengths
1	TJA BSA SLJ	School Athletic population	2	Tuck jump Back squat Standing long jump	Minimal equipment, quick administration, ability to progress, and injury risk factors.
2	TJA RTSB SLJ	School	6	Tuck jump Body weight squat Lunge Push-up Suspended row Standing overhead press Front support with chest touches Standing long jump	Minimal equipment, injury risk factors, school-based movement screen, and multiple AMSC categories.
3	TJA AIMS IMTP	Athletic population	5	Tuck jump Overhead squat Lunge Front support brace and chest touch Press-up Isometric midthigh pull	Injury risk factors, youth athlete-based movement screen, multiple AMSC categories, and strength diagnostics.

AIMS = athlete introductory movement screen; AMSC = athletic motor skill competencies; BSA = back squat assessment; IMTP = isometric midthigh pull; RTSB = resistance training skill battery; SLJ = standing long jump; TJA = tuck jump assessment.

athletes' movement quality in the 4 movements included in the screen. Considering the adaptations developed from the RTSB, the AIMS is quicker and easier to administer than its predecessor; therefore, the screen can be easily standardized in various environments making it feasible to use with large cohorts of children.

PRACTICAL RECOMMENDATIONS FOR IMPLEMENTING ATHLETIC MOTOR SKILL COMPETENCIES ASSESSMENTS

The current review has identified that a variety of reliable movement screens are available to assess AMSC in youth. However, the screens are not synonymous with one another, with varying AMSC categories, fluctuating levels of reliability, different assessment techniques, and in some cases limited implementation within youth-based intervention studies. Therefore, it is pertinent to establish some key principles for practitioners to consider when selecting and performing any movement screen.

Practitioners should recognize which of the AMSC categories they are wishing to examine when selecting a screen. For example, the TJA provides methods to assess jumping, landing, and rebounding mechanics and can be used to identify injury risk factors, whereas the BSA provides in-depth analysis of back squat technique, a movement indicative of lower-body bilateral movement. Both screens can provide valuable insights and in-depth information, but only to individual components of the AMSC spectrum. The RTSB, modified AAA, FGAMA, and AIMS all measure multiple AMSCs and may provide practitioners with a holistic view of a young athlete's ability to move well.

Practitioners should determine which screens have the strongest reliability. The FMS (6,7) and modified TJA (15) are the only assessments that have established both high (ICC $>$ 0.9) interrater and intrarater reliability. The only other screens that have demonstrated good interreliability and intrareliability or above (ICC $>$ 0.8) are the resistance training skill battery (36) and AIMS (58). The RTSB and AIMS have also provided typical errors that can further guide practitioners in the pursuit of meaningful changes in movement competency.

Practitioners assessing movement competency in youth need to be cognizant of examining movement skills in the relevant body segments, across multiple repetitions, inclusive of several AMSCs. The FMS and CSMT are the only screens that do not use a segmental analysis, and both screens implement a best repetition technique to the analysis of movement. Therefore, both of these screens may not be as well equipped for assessing AMSC in comparison to screens that use more granular segmental analyses. Although the RTSB implements the best repetition technique approach to scoring, there is a wealth of supporting evidence for its efficacy to be effectively used in cross-sectional and intervention studies (49–51,63). Furthermore, the screen has been demonstrated to be reliable, valid, and sensitive to interventions in school-based populations (49,51). The FGA-MA can distinguish between talented and nontalented identified athletes; however, if a practitioner places importance on movement consistency across multiple repetitions, the AIMS may provide the most appropriate choice. To aid practitioners in appropriately selecting a movement competency screen, Table 4 provides a summary of the reliability, scoring system, and incorporation of AMSC to help decipher which screen(s) may best suit their needs.

In the authors' opinion, the TJA or its modified version should be considered in all AMSC assessments due to the screen's quick administration, minimal testing equipment requirements, ability to identify injury risk factors, and capability to be implemented with large cohorts in a limited time. If practitioners would like to only assess one movement or have limited time, the BSA is recommended given the fundamental nature of the movement and depth of information derived from the screen. For practitioners working in a school environment, it is recommended that the TJA be used in combination with RTSB. For athletic populations, practitioners can combine the TJA and AIMS as a testing battery. Practitioners wishing to save time in a school environment may also wish to use AIMS as it is quicker to administer as the overhead press and suspended row are removed, with the latter requiring standardization when setting up. In addition, due to the correlations between movement competency and muscular strength and fitness identified by this review, practitioners should consider implementing a strength measure like the isometric midthigh pull to complement the assessment of movement competency. Therefore, implementing the TJA, AIMS, and the isometric midthigh pull would provide practitioners with information pertaining to modifiable risk factors, injury risk, and competency in multiple AMSCs and hence could be considered a comprehensive testing battery for assessing AMSC in youth. In the absence of testing equipment for strength diagnostics, a standing long jump could be used to assess lower limb strength in youth with previously demonstrated reliability (ICC = 0.94) (13). A summary of the recommended movement screen batteries has been summarized in Table 5.

Testing large groups of athletes can be challenging, and practitioners will need to make decisions not only based on what assessments might be most useful but also what time and resources will allow. Although assessing movement competency can potentially be time consuming, recording participants performing the test can be time saving (removing the requirement to rate movement quality in real time while testing). The use of pause and slow-motion replays on video recordings can also aid with precision of rating done at a time of convenience to the practitioner. Where resources allow, multiple stations can be set up where young athletes can move around stations on a carousel basis, although it is still recommended to video record AMSC testing and where possible, to then use a single rater to assess each participant. Where multiple raters are used, the same rater should always rate the same athletes when assessing longitudinally. A carousel setup can also help where practitioners want to capture other relevant data, which could include stations to measure anthropometry to assess size, growth, and somatic maturity and stations to measure strength (e.g., isometric midthigh pull) and/or power (e.g., horizontal jump).

CONCLUSION

Assessing AMSC is an important consideration for practitioners as movement competency is central to the long-term athletic development of youth (31). Using a screen to assess AMSC provides information to guide practitioners in individualized exercise prescription.

There are a number of reliable screens that can assess AMSC in youth populations. Each screen included in this review has its strengths and weakness in terms of assessing movement competency. This review has further identified potential limitations to the feasibility of implementing movement competency screens in youth sport environments. To that end, practitioners should consider their context and needs when selecting a movement screen or consider using a combination of multiple screens to develop a comprehensive understanding of the youth's level of athletic motor skill competency.

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