Table 1. Scoring and operational definitions for the *A*ssessment of biome*C*hanical *E*fficiency *S*ystem (*ACES*)

Phase	ACES Item	Rationale for including item (literature reference)	Camera View	Error Condition	ACES Scoring Guide	ACES Score	N	%
I. Windup* (begins with first motion, ends with max knee lift)	1. Center of gravity (COG) over back (stance) leg? (Y/N) 2. Maximum knee height ≥ 90°? (Y/N) 3. Premature forward momentum (lead hip)—"*leading with the hips*"? (Y/N)	1. Maintaining COG over back (stance) leg allows generation of maximum momentum once forward motion is initiated. If pitcher's body & momentum fall forward prematurely, the kinetic chain is disrupted, resulting in greater shoulder force necessary to generate ball velocity.[1,2] If COG is positioned too far posteriorly or anteriorly, the body segment sequence timing & torque transfer in the kinetic chain will be transferred to the upper extremity, thus predisposing the shoulder and elbow to injury.[3] 2. Maximal lead knee height (preferably with lead hip flexion ≥ 90°) is critical to generate potential energy.[4] 3. While a "strong energy angle" created through early initiation of forward momentum can be an integral component of pitching mechanics at the elite level, *leading with the hips* can be associated with higher humeral internal rotation torque (HIRT), higher elbow valgus load (EVL), and lower pitching efficiency in adolescent pitchers.[5]	Side, Front	1. No 2. No 3. Yes	1. Y=0, N=1 2. Y=0, N=1 **3. N=0, Y=1** (maximum **3** errors)			

II. Stride (begins with lead leg moving towards target)	4. Arms/hands separate equally, symmetrically, with bilateral shoulder abduction (~90°)? (Y/N) 5. Lead (stride) hip externally rotates, back (stance) hip internally rotates? *Both conditions must be met* (Y/N) 6. Hand on-top position (rather than hand under-ball)? (Y/N) 7. Does pitcher complete first forward movement (lead hip moving forward following max knee height) to stride foot contact within 0.95-1.05 seconds? (Y/N)	4. During stride phase, the hands and arms separate, generating linear velocity toward home plate, with the throwing hand separating from the gloved hand so the throwing arm is synchronized with the stride leg motions.[4] Pitchers should have the same angle of bend for both the pitching arm and the glove-side arm, so they appear opposite while mirroring each other. This symmetry serves to preserve balance throughout the delivery.[6] 5. Lack of stance hip internal rotation can lead to premature “opening up” (premature pelvic rotation), leading to inefficient kinetic energy transfer from the pelvis to the trunk, increasing demands on the distal kinetic chain (shoulder, elbow) to maintain accuracy and ball velocity.[4,7] 6. *Hand-on-top position* during arm separation has been associated with lower HIRT, lower EVL, and higher pitching efficiency.[5] *Hand-under-ball position* (delayed glenohumeral abduction, early external rotation) during stride phase may lead to the throwing arm being “late” in the pitching motion. Excessive horizontal abduction, or hyperangulation, can be a contributor to throwing shoulder injuries.[5] 7. If a pitcher does not complete the initial links of the kinetic chain culminating with stride foot contact in < 1.05 seconds, the subsequent events following stride foot contact are likely to fall out of sequence, resulting in decreased performance and increased injury risk.[6]	Side	4. No 5. No 6. No 7. No	4. Y=0, N=1 5. Y=0, N=1 6. Y=0, N=1 7. Y=0, N=1 (maximum **4** errors)			

III. Stride- Foot Contact (first frame after stride foot hits ground)	8. At stride foot contact (SFC), the throwing arm is semi-cocked with the elbow flexed, the shoulder is abducted and externally rotated? *All 3 conditions must be met* (Y/N) 9. Stride length ≥75-85% of height? (Y, N) 10. Lead shoulder position is slightly closed (eg, 3rd base side for RHP), in line with stance foot and home plate? Stride foot position towards home plate or slightly closed? Stride foot pointed slightly inward*? All 3 conditions must be met (*Y, N) 11. Trunk rotation delayed until after SFC? (Y, N)	8. At SFC, throwing shoulder is abducted ~ 90°.[8] Fleisig et al. have demonstrated in analysis of 23 youth (10-15 yo) and 33 high school (15-20 yo) healthy male pitchers, shoulder ER is 67±28° and 64±25°, respectively. Elbow flexion is 74±17° and 82±17°, respectively.[9] 9. Fleisig et al. have demonstrated in analysis of 23 youth (10-15 yo) and 33 high school (15-20 yo) healthy male pitchers, stride length is 85±8% and 85±9%, respectively.[9] 10. Lead shoulder being in a closed shoulder position (pointing toward home plate at stride foot contact), when performed concurrently with *hand-on-top position* in youth and adolescent pitchers, resulted in more efficient pitching mechanics (lower normalized humeral internal rotation torque/velocity and lower normalized elbow valgus load/velocity) than those pitchers who performed both parameters incorrectly.[5] The stride (lead) leg and stance leg should be roughly in line with each other and with the target, ideally with the stride foot in a slightly closed position, with the stride foot angled slightly towards the 3rd base line for right handers, slightly towards the 1st base line for left handers. Normative mechanics for stride foot position are 19 ± 14 cm closed at SFC, and 19° ± 11° closed for foot angle at SFC.[10] 11. Delaying the initiation of trunk rotation until after SFC ensures that the hips have rotated far enough to generate hip-shoulder separation, which is thought to be responsible for 80% of ball velocity during the pitching cycle.[6]	Side, Front, Rear	8. No 9. No 10. No 11. No	8. Y=0, N=1 9. Y=0, N=1 10. Y=0, N=1 11. Y=0, N=1 (maximum **4** errors)			

IV. Arm Cocking (begins with SFC, ends with max ER)	12. Avoid excessive contralateral tilt (mean 24°±10°)? (Y/N) 13. Max ER ≥150-180°? (Y/N)	12. Solomito et al studied 99 college pitchers (DI, DIII) and found the average lateral trunk lean ROM was 24°±10°. Excessive contralateral trunk lean increases glenohumeral joint moment and elbow varus joint moment significantly more than the minimal gain in ball velocity achieved by this posturing.[11] Oyama et al studied 72 high school pitchers, and found that increased contralateral lean was associated with higher ball velocities and joint moments compared to pitchers who didn't demonstrate lean. Oyama et al did not describe the associations between trunk lean, ball velocity, and glenohumeral/elbow moments.[12] 13. At the end of arm cocking phase, the shoulder is externally rotated between 150-180°.[7]	Side, Front	12. No 13. No	12. Y=0, N=1 13. Y=0, N=1 (maximum **2** errors)			
V. Acceleration (begins with max ER, ends with ball release)	14. Forward trunk tilt (mean 32-55°)? (Y/N) 15. Lead leg knee flexed in acceleration, then extending at Ball release? *Both conditions must be met* (Y/N)	14. Forward trunk tilt during acceleration has been associated with increased ball velocity. Forward trunk tilt reaches a mean of 32-55° at ball release.[13] 15. Less maximum lead knee flexion angular velocity, increased knee extension (mean 58° knee extension at ball release), and knee extension angular velocity at ball release are associated with increased velocity.[13,14]	Side, Front	14. No 15. No	14. Y=0, N=1 15. Y=0, N=1 (maximum **2** errors)			
VI. Deceleration (begins with ball release, ends with max IR)	**16.** Shoulder IR continues after ball release? (Y/N) **17.** Lead knee extension continues after ball release? (Y/N)	16. During deceleration, the posterior shoulder musculature must dissipate the forces generated to propel the ball forward. Slowing the upper extremity, which IR velocities of 7000 to 9000 degrees per second, generates distraction forces of as high as 81% of body weight.[13,15] 17. Less maximum lead knee flexion angular velocity, increased knee extension (mean 58° knee extension at ball release), and knee extension angular velocity at ball release are associated with increased velocity.[13,14]	Side, Front	16. No 17. No	16. Y=0, N=1 17. Y=0, N=1 (maximum **2** errors)			

VII. Follow-through (begins with max IR, ends with arm across body)	**18.** Arm crosses body diagonally, without sidearm or submarining? (Y/N) **19.** Trunk flexes forward? (Y/N)	18. Arm slot/path tends to occur naturally and is a function of posture, determined by trunk tilt, shoulder abduction, and elbow flexion.[6,16] Conventionally, an 11-5 or 1-7 arm ("over the top" or "overhand") path is preferred, as a higher release point results in creation of a downward plane/angle, resulting in higher groundball rates. However, balance and posture during delivery are the priorities rather than arm slot (exception: sidearm/submarine is *not* acceptable). Many pitchers release at a ¾ arm slot, which is also acceptable.[7] Adult pitchers who throw at ¾ or overhand arm slots demonstrate significantly less elbow varus torque than sidearm pitchers.[16] 19. A long arc of deceleration from the throwing arm, trunk flexion, and lead knee extension allow energy to absorbed by the trunk and legs, reducing stress placed on the throwing arm by transferring most of the weight and momentum of the body to the lead leg.[7] If energy created to propel the ball to the target cannot be adequately dissipated during deceleration and follow-through, overuse injuries (typically posterior arm, trunk) may be incurred.[4]	Front, Rear	18. No 19. No	18. Y=0, N=1 19. Y=0, N=1 (maximum **2** errors)			
VIII. Overall Impression	20. Is the pitcher stable, balanced, maintaining head control, eyes focusing on target throughout delivery, finishing in a balanced fielding position?	20. If a pitcher does not stay dynamically balanced (e.g., head over center of mass) with minimum head movement or postural change throughout the delivery, every inch of inappropriate head movement will cause up to two inches at ball release, resulting in an inefficient motion, discoordination of the kinetic chain, and ultimately increased injury risk and decreased performance.[6]	Front, Side, Rear		20. Excellent=0, Average=1, Poor=2			
				Total Score:				

*Pitcher may initiate windup from the stretch, but slide-step technique should not be utilized for purposes of this assessment.

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