Hand Reach Star Excursion Balance Test as a Measure of Joint Mobility

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1 OBJECTIVES

Joint range of motion (ROM) is commonly measured using goniometry with accepted reference values such as American Academy of Orthopedic Surgeons (AAOS) (Greene and Heckman, 1994). The procedures of obtaining these measures are based on unidirectional and uniplanar passive testing of isolated joint motions in supine, prone or seated positions.

The relationship of such ROM measures to performance have been found to be variable (Craib et al., 1996; Menz et al., 2006). Utilizing tests of the full kinematic chain from an upright standing position that involve the concurrent use of multiple joints, directions and planes of motion might be one solution to the shortcomings of the traditional ROM testing procedures. Full kinematic chain tests have the advantage of greater specificity to most human movements such as athletic performance.

The Star Excursion Balance Test (SEBT) is a widely accepted test of dynamic postural control and balance (Gribble et al., 2012) that challenges coordination, mobility, and strength (Hubbard et al., 2007). However it does not challenge all joint movements at and above the hip (Delahunt et al., 2013), but it offers a platform from which a whole-body mobility and balance test can be created. In the current study we propose a Hand Reach Star Excursion Balance Test (HSEBT), which combines a systematic use of unilateral and bilateral hand reaches, thus also challenging mobility in hip and upper body joints.

The purposes of this study were to (1) provide joint movement reference data for HSEBT; and (2) compare the 22 elicited joint movements of the ankle, knee, hip and spine elicited by HSEBT to ROM reference values and joint movements elicited by SEBT.

2 METHODS

Twenty-eight healthy male subjects without musculoskeletal dysfunction in the past 6 months volunteered for the study. HSEBT was performed on a testing grid that featured nine concentric circles at 10 cm intervals with eight vectors projecting from the centre of the mat at 45° intervals and marked at one centimetre intervals. The vectors were used as reference for the horizontal reach tests (HR) and named as follows: 1) Anterior (A0). 2) Left 45° (L45). 3) Right 45° (R45). 4) Left 90° (L90). 5) Right 90° (R90). 6) Left 135° (L135). 7) Right 135° (R135) and 8) Posterior (P180). All HR are measured in centimetres (cm). The rotational reaches (RR) were measured in degrees (°) using the outer concentric circle with degrees identified at 5° intervals. When performing overhead or rotational reaches a plumbline was used to project reach distance to the mat. All subjects performed 20 hand reaches, 10 on each leg, in the same order without warming up.

Movements of the participants were captured using 58 reflective markers and fifteen Oqus cameras (ProReflex®, Qualisys Inc., Gothenburg, Sweden) recording at 480 Hz to create the foot, leg, thigh, pelvis, thorax and upper arm segment. Data analysis was performed using Visual 3D® (C-Motion Inc., Rockwille MD, USA).

Three-dimensional joint movements of the foot, knee, hip and trunk ($\theta=\varphi_{max}-\varphi_{start}$) triggered by different hand reach tests were calculated from starting (φ_{start} = $mean_{frames\ 5\text{-}100}$) and maximum reach position (φ_{max}) of the fifth metacarpal marker of the reaching hand(s). The maximum reach position was defined to reflect the maximum HR and RR scores. Descriptive statistics were then calculated for all joint movements and hand reach performance.

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Table 1: HSEBT joint movement comparison to selected ROM reference values.

Joint	Plane	Motion	Test	Result (°)	ROM reference values (°)
Foot	Sag	DF	R45	29.2±6.0[2]	11-27 (Lindsjo et al., 1985; Mudge et al., 2013)
	Sag	PF	LROT	0.4±4.6	36-56 (Boone and Azen, 1979; Lindsjo et al., 1985)
	Front	Ev	R90	18.1±3.2[2]	13-34 Schwarz, 2011 #1564;Macedo, 2009 #1567}
	Front	Inv	L90	7.8±4.4	21-43 (Macedo and Magee, 2009; Schwarz et al., 2011)
	Trans	Abd	RROT	14.2±3.5	NR
	Trans	Add	LROT	16.9±5.1	NR
Knee	Sag	Flex	A0	94.3±22.4	132-149 (Macedo and Magee, 2009; Roach and Miles, 1991)
	Sag	Ext	RROT	7.9±12.8	-2 -4 (Boone and Azen, 1979; Mudge et al., 2013)
	Front	Abd	LROT	5.5±2.4[2]	frontal plane movement arch of 13° at 20° of knee flexion (Levangie and Norkin, 2011).
	Front	Add	R45	18.2±6.9[2]	
	Trans	IR	LROT	15.7±3.7[2]	15 (Almquist et al., 2002)
	Trans	ER	RROT	24.4±5.2[2]	20 (Almquist et al., 2002)
Hip	Sag	Flex	R45	109.0±8.2	113-133 (Macedo and Magee, 2009; Sankar et al., 2012)
	Sag	Ext	L135	30.5±6.9[2]	3-19 (Moreside and McGill, 2011; Roach and Miles, 1991)
	Front	Abd	L90	18.2±7.4	34-60 (Macedo and Magee, 2009; Sankar et al., 2012)
	Front	Add	R90	28.3±5.3[2]	14-31 (Roaas and Andersson, 1982; Sankar et al., 2012)
	Trans	IR	LROT	27.2±5.3[2]	27-58 (Moreside and McGill, 2011; Mudge et al., 2013)
	Trans	ER	RROT	32.2 ±5.4[2]	32-48 (Mudge et al., 2013; Roach and Miles, 1991)
Trunk	Sag	Flex	A0	58.1±9.0	Lumbar: 40-60 Thoracic: 20-45 (Magee, 2006)
	Sag	Ext	P180	35.1±7.8	Lumbar: 20-35 Thoracic: 25-40 (Magee, 2006)
	Front	Lat Flex	L90/R90	38.1±6.7[1, 2]	Lumbar: 15-20 Thoracic: 20-40 (Magee, 2006)
	Trans	Rot	LROT/RROT	33.1±4.3[1]	Lumbar: Rot: 3-18 Thoracic: 35-50 (Magee, 2006)

[1]= kinematic average of two tests
[2]= within or greater than range of ROM reference values
Abbreviations: NR=None Reported; L=Left; R=Right; B=Bilateral; DF=Dorsiflexion; PF=Plantarflexion; Ev=Eversion; Inv=Inversion; Abd=Abduction; Add=Adduction; Flex=Flexion; Ext=Extension; IR=Internal Rotation; ER=External Rotation; Lat Flexion= Lateral flexion; Rot=Rotation

3 RESULTS

Twenty-eight healthy male subjects (age 23.8 ± 2.2 years; height 181 ± 6.0 cm; weight = 78.3 ± 9.2 kg) completed all 20 tests. The HSEBT test that elicited the greatest joint movement, plane and direction, of the ankle, knee, hip and spine is identified in Table 1. HSEBT elicited eleven out of twenty-two joint movements within or greater than goniometric ROM reference values.

4 DISCUSSION

Dorsiflexion (29.2±6.0°) is greater than ROM reference values. However, more appropriate comparisons can be made to the weight bearing modified lunge test (38,2°) (Menz et al., 2003). Foot eversion (18.1±3.2°) is within ROM reference values and similar to the test found to elicit maximum ankle eversion in the SEBT (16.4±1.9°) (Doherty et al., 2015). Inversion (7.8±4.4°) is not within range of ROM reference values, however, similar to what has been found for SEBT (7.1±1.9°) (Kang et al., 2015). To the authors' knowledge no goniometric ROM for abduction and adduction exist, however the joint movements obtained is similar to stance phase of running (Freedman et al., 2015).

Maximum knee flexion (94.3±22.4°) is below ROM reference values, but greater than in the SEBT (66.3°-68.9°) (Doherty et al., 2015; Kang et al., 2015). Knee internal rotation is within the range while external rotation is greater, (7.8°-26.6°) and (5.3±14.7°) respectively, when compared to SEBT (Doherty et al., 2015; Kang et al., 2015). The frontal plane arch (23°) obtained in this study is greater than the ROM reference values (Table 1), but similar to a functional task such as a jump-stop unanticipated cut (27°) (Ford et al., 2005)

HSEBT is eliciting more hip flexion than the SEBT (72.0°-77.0°) (Doherty et al., 2015; Kang et al., 2015). Hip extension is greater than ROM reference values, but closer to what have been observed in activities thought to require hip extension such as sprint running (22°) (Kivi et al.,

2002) and football kick (25°) (Smith and Gilleard, 2015). In comparison, SEBT does not challenge hip extension. Both hip internal and external rotation are at the lower end of ROM reference values. The rotational values are greater than the internal (4.3°-8.0°) and external rotation (5.2°-23.5°) values reported for the SEBT (Doherty et al., 2015; Kang et al., 2015; Robinson and Gribble, 2008). Hip adduction is within ROM reference values and greater than what has been found with the SEBT (15°) (Doherty et al., 2015). Hip abduction is less than ROM reference values, but similar to SEBT (15°) (Robinson and Gribble, 2008).

Spine movements elicited by the HSEBT are representative of both lumbar and thoracic spine movement. The HSEBT is able to elicit flexion and lateral flexion within, and extension, and rotation just outside range of ROM reference values (Magee, 2006). SEBT do not elicit spine movements within ROM reference values. However, selected movements do predict reach distance (Kang et al., 2015), which might indicate their importance in balance and postural adjustments.

HSEBT elicits unique combinations of movements in ankle joint complex, knee, hip and spine. Observed joint movements, nine of twenty-two possible, were within the ranges of goniometric ROM reference values, while two (ankle dorsiflexion and hip extension) where greater. In comparison to the SEBT, the HSEBT elicits similar or lower values for the ankle, but greater values for the knee, hip and spine. In addition, hip extension and spine movements are elicited by the HSEBT and not SEBT. HSEBT offers a new and promising approach to functional mobility testing that integrates the full kinematic chain.

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