Ergonomics

ISSN: 0014-0139 (Print) 1366-5847 (Online) Journal homepage: http://www.tandfonline.com/loi/terg20

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To cite this article: David Frost , Jordan Andersen , Thomas Lam , Tim Finlay , Kevin Darby & Stuart McGill (2013) The relationship between general measures of fitness, passive range of motion and whole-body movement quality, Ergonomics, 56:4, 637-649, DOI: 10.1080/00140139.2011.620177

To link to this article: http://dx.doi.org/10.1080/00140139.2011.620177

Published online: 31 Jan 2012.

Ergonomics, 2013
Vol. 56, No. 4, 637–649, http://dx.doi.org/10.1080/00140139.2011.620177

The relationship between general measures of fitness, passive range of motion and whole-body movement quality

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(*Received 22 December 2010; final version received 29 August 2011*)

The goal of this study was to establish relationships between fitness (torso endurance, grip strength and pull-ups), hip range of motion (ROM) (extension, flexion, internal and external rotation) and movement quality in an occupational group with physical work demands. Fifty-three men from the emergency task force of a major city police force were investigated. The movement screen comprised standing and seated posture, gait, segmental spine motion and 14 tasks designed to challenge whole-body coordination. Relationships were established between each whole-body movement task, the measures of strength, endurance and ROM. In general, fitness and ROM were not strongly related to the movement quality of any task. This has implications for worker training, in that strategies developed to improve ROM or strength about a joint may not enhance movement quality.

Practitioner Summary: Worker-centered injury prevention can be described as *fitting workers to tasks* by improving fitness and modifying movement patterns; however, the current results show weak correlations between strength, endurance and ROM, and the way individuals move. Therefore, the development of occupation-specific injury prevention strategies may require both fitness and movement-oriented objectives.

Keywords: movement screen; police force; injury; strength; torso endurance

1. Introduction

Fitness testing within the rubric of risk factors for subsequent injury has traditionally assessed variables of strength (Knapik et al. 1991, 2001), joint range of motion (ROM) (Van Dillen et al. 2008) and physiological variables such as heart rate, blood pressure and/or oxygen uptake. Very few have attempted to quantify movement quality as a predictor of injury. This is surprising when one of the most identified links to injury is having had a previous injury (Greene et al. 2001; McGill 2007). Injury changes the way a person moves as an accommodation to pain (consider limping from foot pain which changes the mechanics throughout the anatomical linkage). Injury leading to a loss of function is associated with modified movement patterns (McGill et al. 2003). Other markers for injury include hamstring flexibility (Knapik et al. 2001) and asymmetrical joint ROM. For example, Hellsing (1988) found that asymmetrical hamstring tightness was a predictor of future back injury amongst soldiers. The way that an individual moves has an important influence on injury criteria such as joint and tissue load. Further, movement technique influences the length of time and repetitions a worker is able to perform a task with uncompromised form to spare the tissues of inordinate load (Brereton and McGill 1999). Given the variety of considerations for interpreting the links between movement and potential injury, more understanding of movement is needed.

Study of fitness in occupational groups has suggested that being fit, at least using a physiological definition based on energy system markers, is generally associated with fewer injuries (e.g. Cady et al. 1979, using a large cohort of firefighters). However, attempting to improve fitness alone may not be the most appropriate strategy to prevent injuries; Jones et al. (1993) reported that 46% of US Army trainees undergoing 12-weeks of basic training experienced an injury. Among the several possible explanations is that the movement flaws that were not addressed by simply being fitter, or stronger in a traditional sense, caused repetitive joint stresses leading to injury. This motivated attempts to quantify movement in a systematic way. However, this is difficult because the criterion of 'good movement' depends on the context. For example, the movement objective to prevent falls in an elderly woman would be very different than the movement required to carry that same woman down a flight of apartment stairs. Nonetheless, because movement asymmetry and compromises to neuromuscular control have been linked to injury (Kiesel et al. 2007, 2011; Zazulak et al. 2007), many scientists and practitioners have begun using movement-based screens to expose 'faulty' or 'aberrant' patterns that might predispose individuals to injury (Cook et al. 2006a; Luomajoki et al. 2008; Harris-Hayes and Van Dillen 2009; Kritz et al. 2009; Padua et al. 2009). Rarely, however, are the results from these screens compared to common indices of fitness or joint

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ROM. The goal of this study was to examine the relationship between traditional measures of fitness (i.e. strength, endurance and ROM) and whole-body movement screen scores in a physically demanding occupational group. It was hoped that exploring the links between various tests would reveal relationships that could assist to identify the most influential variables to be included in future studies.

It was hypothesised that:

(1) Muscular strength and endurance would not be related to the quality of an individual's movement.
(2) Passive joint ROM would not be related to the quality of an individual's movement.

2. Methods

2.1. Subjects

Fifty-three men, all members of the emergency task force of a major city police department were recruited. Each individual was chosen to participate because they performed a physically demanding job and engaged in regular physical training sessions focussed on strength and endurance enhancement. The subject's mean (± SD) age, height, body mass, active duty and weight training experience were: 37.8 years (5.0), 1.79 m (0.09), 88.7 kg (12.1), 13.4 years (5.2) and 16.3 years (6.0), respectively. Each participant read and signed an informed consent approved by the University Office for Research Ethics.

2.2. Data collection

Each testing session lasted approximately 2.5 h. Personal information was recorded and participants were randomly assigned to begin with the fitness, ROM or movement screen portion of the evaluation. Specific tasks within each group of tests were also performed in random fashion.

2.3. Fitness testing

The fitness test was structured to evaluate static muscular endurance (static sit-up posture (SIT), front and side planks and Biering-Sorensen extension) and strength (grip strength (GRP) and pull-ups to fatigue) (Figure 1). Each task was administered with the following guidelines: (1) SIT – participants adopted a sit-up posture with the knees and hips flexed and the arms folded across the chest. The back (neutral spine) was placed against a box angled 55° from the floor. The test began when the box was pulled away from the back and ended when a neutral spine posture could no longer be maintained. The feet were secured for the duration of the test (McGill et al. 2010); (2) front plank (FPLK) – from a prone position, participants bridged themselves off the ground (elbows and toes) and maintained a neutral spine position for as long as

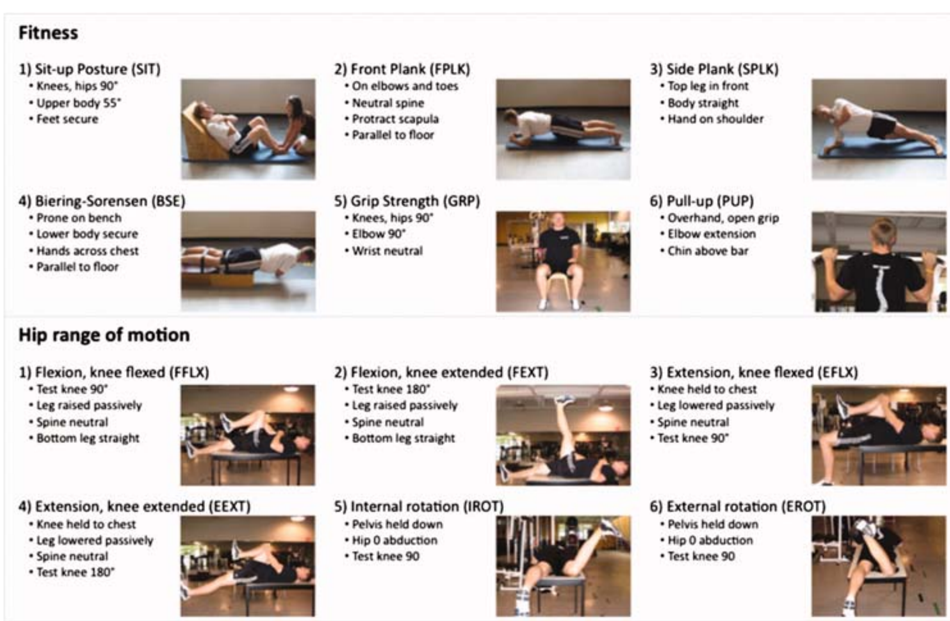

Figure 1. Administration procedures for the fitness and hip range of motion tests.

possible. The test was ended when the position could no longer be held; (3) side plank (SPLK) – from a side lying position, participants raised themselves off the floor with their elbow and feet (top foot was placed in front of bottom). A straight-body position was maintained for as long as possible and the test was ended when the posture could no longer be held; (4) Beiring-Sorensen extension (BSE) – the upper-body was cantilevered out over the end of a bench and the pelvis, knees and hips were secured. The upper arms were crossed and held across the chest while a straight-body position was held as long as possible. The test was ended when the horizontal position could no longer be maintained; (5) GRP – participants were seated on a chair of standard height without armrests. The shoulder was adducted, the elbow flexed to 90° and the wrist placed in a neutral position (Harkonen et al. 1993). A hand dynamometer (Takei Kiki Kogyo, Nigata, Japan) was used to record three maximal effort trials with each hand, in an alternating fashion. The highest value was used for analysis; (6) pull-ups (PUP) – using an overhand grip and a normalised hand position of shoulder width, participants were asked to perform pull-ups until fatigue. Cadence was not controlled; however, the chin was required to reach hand height for the repetition to be recorded. Approximately, 5 min of rest was given between each task.

2.4. ROM testing

Passive hip ROM (flexion, extension and internal and external rotation) was assessed with six tests (Figure 1): (1) hip flexion (knee flexed) (FFLX) – lying supine on a bench with a neutral spine and the non-test leg fully extended, the test leg was placed in 90° knee flexion and raised by the research assistant until spine motion was noted. Hip flexion was recorded as the angle between the horizontal and a line between the greater trochanter and the lateral epicondyle of the femur; (2) hip flexion (knee extended) (FEXT) – the test leg was extended (0° knee flexion) and a second hip flexion measurement was taken; (3) hip extension (knee flexed) (EFLX) – lying supine with the non-test leg's hip and knee flexed (i.e. Thomas test position), the research assistant ensured that the spine was in a neutral position. The test leg's knee was flexed to 90° and lowered passively. Hip extension was recorded as the angle between the horizontal and a line between the greater trochanter and the lateral epicondyle of the femur (positive was greater ROM); (4) hip extension (knee extended) (EEXT) – the test leg was extended (0° knee flexion) and a second hip extension measurement was taken; (5) hip internal rotation (IROT) – lying prone, the hips were placed at 0° abduction and the test knee was flexed to 90°. The research assistant passively guided the hip into internal rotation, and a measurement was taken between the vertical and the shank; and (6) hip external rotation (EROT) – lying prone, the hips were placed at 0° abduction and the test knee was flexed to 90°. The research assistant passively guided the hip into external rotation, and a measurement was taken between the vertical and the shank. Each ROM measurement was taken with a goniometer.

2.5. Movement screening

Movement quality was assessed with 20 general tasks (Figure 2a,b). Seven comprised the Functional Movement Screen™ (FMS) (tasks 1–7), a formalised screen that has shown some efficacy in the prediction of injuries (Kiesel et al. 2007), and were administered with specific instructions. The remaining 13 movements were chosen to reflect tasks often used by clinicians or Kinesiologists to evaluate injury risk or return to work status. The 20 tasks were: (1) deep squat (SQT) – a dowel was placed over head with the arms outstretched as the individual squatted as low as possible; (2) hurdle step (HRD) – a dowel was placed across the shoulders and the individual stepped over a hurdle (tibial tuberosity height) placed directly in front of them; (3) in-line lunge (LNG) – with the feet aligned and a dowel contacting the head, upper back and sacrum, the participant performed a split squat; (4) shoulder mobility (SHDR) – the individual attempted to touch their fists together behind their back (internal and external shoulder rotation); (5) active straight leg raise (SLR) – while lying supine on the ground the individual actively raised one leg as high as possible while the other leg remained in contact with the ground; (6) trunk stability push-up (PUSH) – the participant performed a push-up with their hands shoulder width apart; (7) rotary stability (ROT) – the individual assumed a quadruped position and attempted to touch his knee and elbow, first on the same side of the body and then on the opposite. 'Clearing' tests were included with the SHDR, PUSH and ROT tasks to expose other potential sources of pain; (8) standing posture (POS) – the participant stood in a relaxed position with his arms at the side; (9) seated posture (SPOS) – the participant sat on a box (0.40 m in height) in a relaxed manner with his arms on his lap; (10) segmental flexion (FLEX) – from standing, the individual bent forward as far as was comfortable; (11) segmental extension (EXT) – from standing, the individual bent backward, reaching over head with their arms, as far as was comfortable; (12) segmental lateral bend (BEND) – from standing, the individual bent laterally as far as was comfortable; (13) Segmental twist (TWST) – from standing, the individual twisted about the hips and spine as far as was comfortable; (14) gait (GAIT) – the participant walked 10 paces; (15) box lift (BOX) – from standing, a light-weight (approximately 2 kg) box ($0.33 \times 0.33 \times 0.28$ m) was lifted to waist height and returned to the ground; (16) coin lift (COIN) – from

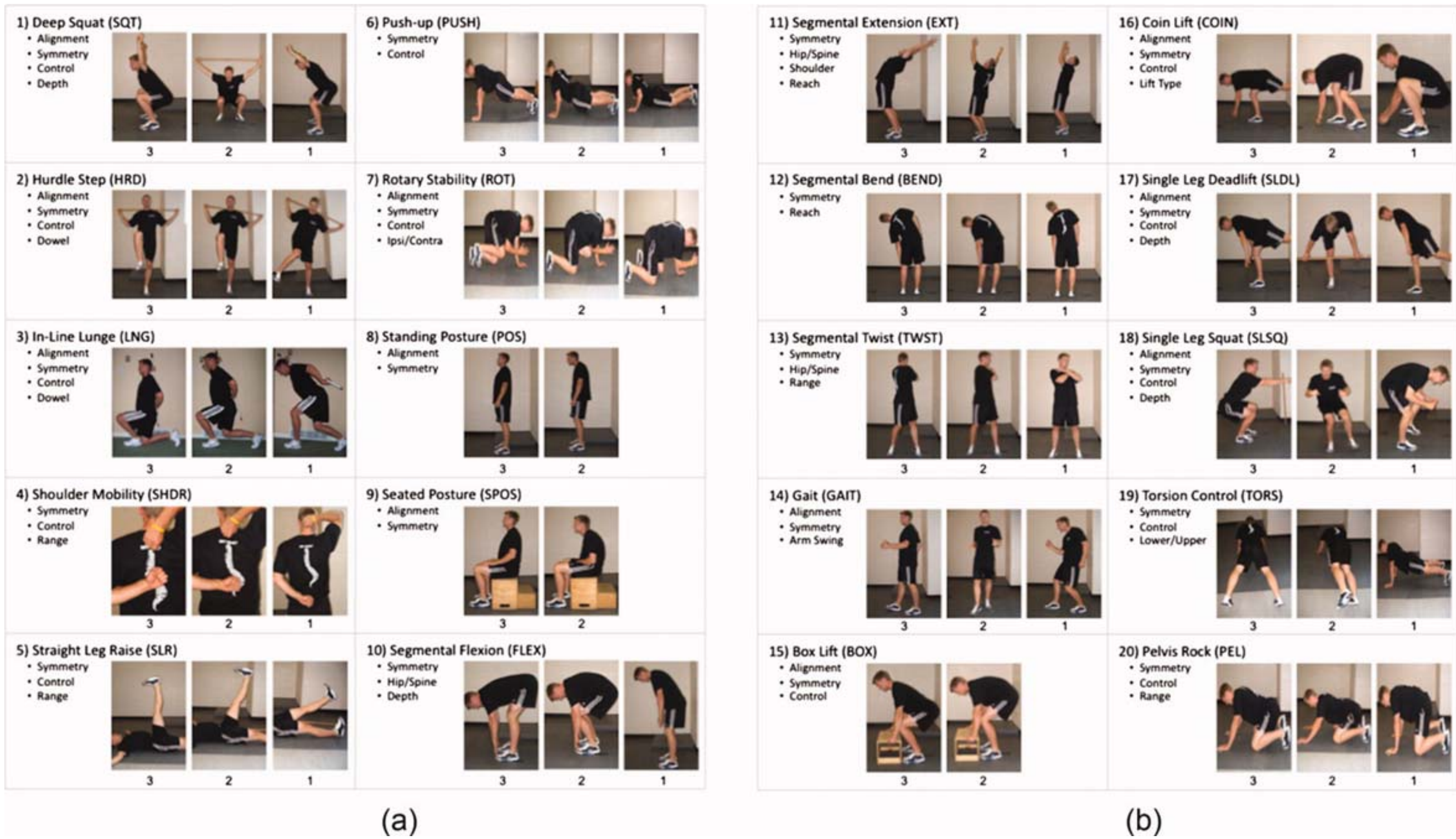

Figure 2. (a) Tasks 1–10 included in the movement screen. Examples of a '3' (no compensation), '2' (compensation) and '1' (cannot perform according to relevant criteria) are shown. (b) Tasks 11–20 included in the movement screen. Examples of a '3' (no compensation), '2' (compensation) and '1' (cannot perform according to relevant criteria) are shown.

standing, a coin was picked up off the floor; (17) single leg deadlift (SLDL) – the individual balanced on one leg with a dowel in his hands and bent over as far as was comfortable; (18) single leg squat (SLSQ) – the individual balanced on one leg and squatted down as low as was comfortable; (19) torsion control (TORS) – while bridging off the floor (hands and toes) one arm was lifted off the ground. The task was also performed by lifting each leg off the ground; (20) pelvis rock (PEL) – beginning in a quadruped position, the individual rocked his pelvis back towards his heels while keeping the hands on the ground.

2.6. *Data analyses*

Movement quality was described with an approach similar to that used by Cook et al. (2006a, 2006b) to grade the FMS. Provided with a list of possible compensatory motions, a rater was instructed to check off those that were observed during the performance of each particular task. Compensatory motion was defined by criteria that have been hypothesised to be predictive of musculoskeletal pain or injury (e.g. spine flexion with hip flexion, a medial collapse of the knee) (Sahrmann 2002; Hewett et al. 2005; McGill 2009; Cook et al. 2010). Screening criteria for five tasks can be found in Table 1. The inter-rater reliability for this type of screen has shown to be high (Minick et al. 2010, Frohm et al. in press); therefore, one clinician with 5 years of movement screening experience provided all observations. To avoid any bias in assigning grades, this data was then tabulated by the researchers and used to assign scores of 0–3 to each task (based on explicit criteria) to differentiate between movements performed with or without compensatory motion and pain. A three, two, one and zero represented performed without compensation (according to relevant criteria), performed with compensation, could not perform (according to relevant criteria) or pain, respectively. Tasks requiring performances of the left and right side of the body were given a grade equal to that of the lowest score. The cumulative sum of all 20 tasks was defined as the total movement score (TOT).

2.7. *Statistical analyses*

Means and standard deviations were computed for each strength, endurance and ROM variable. The relationship between all movement tasks (and TOT) and the movement tasks and each measure of strength, endurance and ROM were evaluated with either a Pearson or Spearman rank-order correlation depending on the distribution of the data (data was tested for normality). The strength of the effect size for all correlations was defined by the thresholds provided by Cohen (1992): small (low), $r = 0.10$; medium (moderate), $r = 0.30$; large (strong), $r = 0.50$. Significance was set at 0.05.

3. Results

The mean and standard deviation of each endurance, strength and hip ROM variable are presented in Figure 3. Figure 4 illustrates the distribution of scores (0–3) for all 20 movement screen tasks.

3.1. *Movement tasks*

The correlations between all movement tasks can be found in Table 2. The LNG and SQT were found to have the strongest ($p < 0.05$) relationship with the TOT ($r = 0.65$ and $r = 0.55$, respectively). Four of the 20 (i.e. LNG, TWST, BOX and SLSQ) tasks exhibited significant correlations with at least seven other movements, while three of the movements tested (POS, FLEX and COIN) had no relationship with any other task.

3.2. *Fitness and movement*

The correlations between all fitness variables and movement tasks can be found in Table 3. Relationships ($p < 0.05$) were noted between six of the eight fitness variables (not FPLK or right GRP) and at least one movement task; the SIT, left GRP and PUP were correlated with one, the BSE with two, and the right and left side PLNK with three each, though they were not the same three tasks for each side of the body, and in the two instances where they were half of the correlations were negative (with PUSH).

The two tasks demonstrating the strongest correlations with the TOT (SQT and LNG) were related ($p < 0.05$) to at least one fitness variable; however, in both cases the relationship was only present on one side of the body (left GRP and left SPLK for the SQT and LNG, respectively). In general, few correlations were noted between strength or endurance and movement quality.

Table 1. Grading criteria for five movement tasks.

Movement	Shoulders/scapula/upper limbs	Trunk/pelvis	Hips/lower limbs
Segmental flexion (FLEX)		Noticeable rotation of trunk/pelvis Initiated motion with spine Limited/exaggerated lumbar spine motion Limited/exaggerated thoracic spine motion	Did not reach toes*
Segmental extension (EXT)	Shoulder flexion limited (elbow not past ears) Mid hand does not fall behind shoulders Spine of scapula is posterior to heels*	Noticeable rotation of trunk/pelvis Noticeable reduction in thoracic extension	ASIS does not clear toes* Heels do not remain on the floor*
Single leg squat (SLSQ)	Shoulder elevation Torso is not parallel to shin Cannot perform/squat past 135° knee flexion*	Lateral deviation of trunk Lumbar flexion noted prior to hip flexion	Equal hip height not maintained Hip, knee and foot are not aligned Pronation/supination of foot Internal/external rotation of foot
Deep squat (SQT)	Dowel outside base of support* Torso is not parallel to shins Exaggerated shoulder elevation Cannot perform*	Excess lumbar flexion/extension Limited thoracic extension Pelvis tilts/rotates to one side	Hips, knees and feet are not aligned Thighs are not below horizontal* Feet internally/externally rotate
In-line lunge (LNG)	Dowel loses contact with sacrum, back or head Loses balance/cannot perform*	Trunk movement Exaggerated lumbar extension Lumbar flexion	Front knee aligned with hip and foot Knee fails to contact heel of front foot Front heel comes off the floor Rear foot externally rotates

Notes: Participants received a '3' if no compensations were noted; participants received a '2' if any compensation was noted, aside from those marked with *; participants received a '1' if they demonstrated a compensation marked with *.

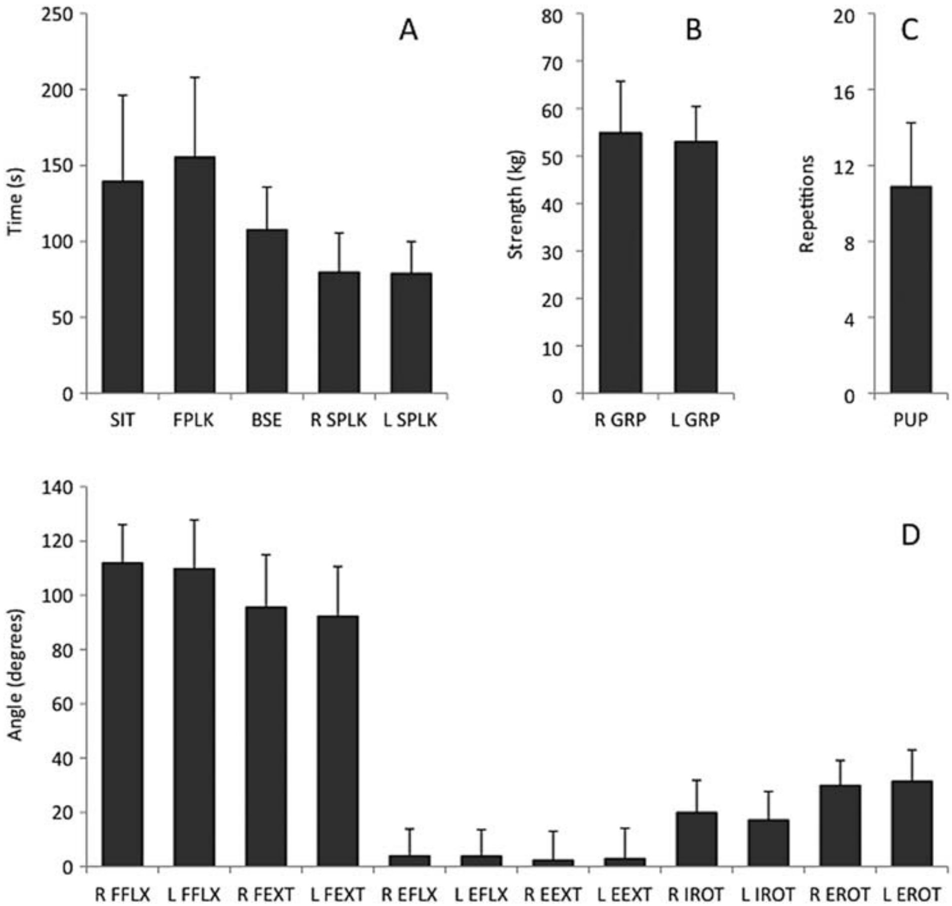

Figure 3. The mean and standard deviation of variables related to: (A) trunk endurance, (B) grip strength, (C) pull-ups and (4) hip range of motion. The right and left sides are denoted by an 'R' and 'L', respectively. (SIT, static sit-up posture; FPLK, front plank; SPLK, side plank; BSE, Beiring-Sorenson extension; GRP, grip strength; PUP, pull-ups; FFLX, hip flexion (knee flexed); FEXT, hip flexion (knee extended); EFLX, hip extension (knee flexed); EEXT, hip extension (knee extended); IROT, hip internal rotation; EROT, hip external rotation.)

3.3. ROM and movement

All six ROM measures were found to correlate ($p < 0.05$) with at least one of the 20 movement tasks (Table 4). However, of the 19 total relationships found to be significant, 12 were asymmetrical in nature (i.e. the right and left side correlations were not both significant). Four of the six ROM measures (FFLX, FEXT, EFLX and EEXT) were found to correlate moderately ($p < 0.05$) with the TOT (Table 4); but like the individual movement tasks, only EFLX ($r = 0.30$ and $r = 0.33$ for the right and left side correlations, respectively) demonstrated a symmetrical relationship.

Interestingly, SPOS, which was correlated ($p < 0.05$) to only one other movement task (LNG; $r = 0.32$), exhibited moderate correlations ($p < 0.05$) with more ROM measures than any other task, and each was symmetrical (Table 4). The SQT was moderately correlated to right and left FEXT, but the LNG did not relate to any ROM measure. In general, a strong relationship was not found between ROM and movement quality.

4. Discussion

The quality of an individual's movement has probably been underappreciated in traditional fitness testing even though it often determines the risk of injury (Hewett et al. 1999; Kiesel et al. 2007) and can enhance performance (McGill 2009). Movement patterns are frequently modified (either voluntarily or involuntarily), in response to the demands of a task or through knowledge gained from previous experiences (Dufek et al. 1995; Hyde and Gengenbach 2007), whether such accommodations are beneficial or not. Consequently, compensatory motion noted during the performance of one task may

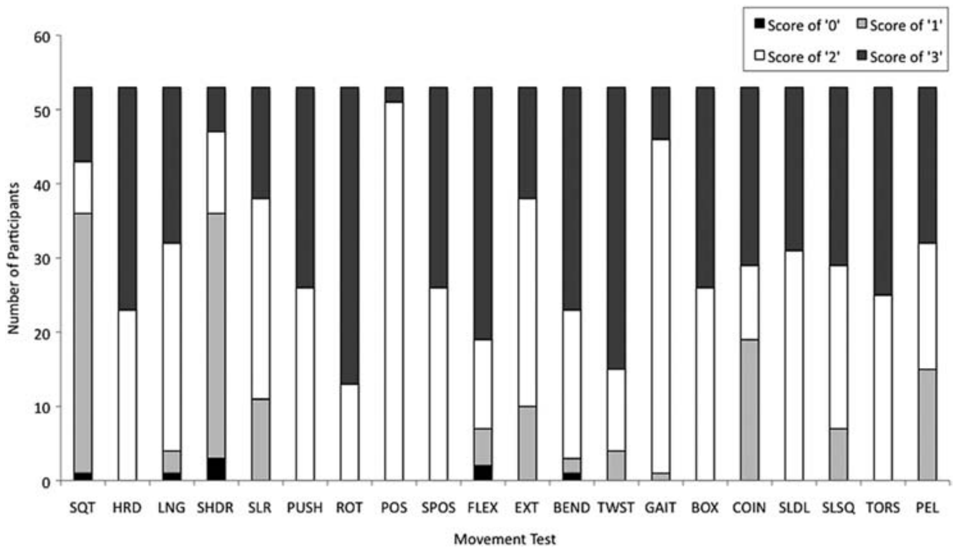

Figure 4. The distribution of movement scores (0–3) for each task. A three, two, one and zero represented performed without compensation, performed with compensation, could not perform and pain, respectively.

also be exposed in another. For example, limited squat depth may reflect a similar issue to that causing exaggerated lumbar flexion in a task such as the box lift or pelvis rock. It is therefore not surprising that the results of this study suggest that the quality of motion in one compound movement better predicts an individual's overall movement competency when compared with measures of joint ROM, muscular strength or endurance. The movement screen used in this study comprised a combination of simple and complex whole-body tasks to provide an impression of overall movement competency. A regression analysis could have been used to identify a grouping of tasks that could best predict this movement score; however, had this study investigated a different population with dissimilar physical demands, it is likely that a different set of tests would have been found to better predictors. Prior to using any movement screen is likely more important to first ask 'who is being screened?' and 'what are they being screened for?'.

The only significant correlation amongst the fitness variables tested and the overall movement score was that of the Biering-Sorensen extension ($r = 0.33$). Poor performance on this test has been cited as a marker for future low back problems (Biering-Sorensen 1984; McGill et al. 2003), although the mechanism by which a relationship might exist is probably not directly related to endurance on the test itself. A more plausible rationale is that superior endurance allows individuals to maintain spine-sparing movement patterns for extended periods of time by delaying the onset of fatigue. Consequently, various high-risk activities, such as repetitive lifting, can be performed safely and in an effective manner. Had the movement screen in this study incorporated a fatigue component, the correlation between extensor endurance and movement quality may have been even stronger and movement quality scores may have been very different.

Weak correlations between the fitness variables measured in this investigation and overall movement quality may provide some justification for claims to be made regarding a general relationship between fitness and movement; however, the findings may also be specific to the tests chosen or the (in)experience of the participants. Testing muscular endurance in isolation or with an isometric task may have limited application as a predictor of performance in dynamic activities (DiMattia et al. 2005; Okada et al. 2011), particularly given that verbal cuing can have an immediate impact on the way that an individual moves (Onate et al. 2001; Barrios et al. 2010; Noehren et al. 2011). Okada et al. (2011) also found that torso endurance (FPLK, SPLK, BES) could not be used to predict movement screen scores (FMS). The researchers suggested the static/dynamic nature of the tasks to be the primary reason for their results. Training strategies designed to improve strength, endurance or power can be extremely beneficial for a number of reasons, but in the absence of movement-oriented feedback there is often little transfer to an individual's movement patterns (Santana et al. 2007; Herman et al. 2008), resulting in minimal attenuation of risk on an unrelated task (Dufek et al. 1995; Hyde and Gengenbach 2007).

A greater percentage of the hip ROM variables were correlated with movement quality, but in most cases significant relationships were only noted for one side of the body, making it difficult to assign relevance to these findings. But, should we expect to see a relationship between passive ROM and the whole-body coordination? The SLR test was included to

Table 2. Correlations between movement tasks.

	SQT	HRD	LNG	SHDR	SLR	PUSH	ROT	POS	SPOS	FLEX	EXT	BEND	TWST	GAIT	BOX	COIN	SLDL	SLSQ	TORS	PEL
SQT	1																			
HRD	0.03	1																		
LNG	0.44	0.43	1																	
SHDR	0.35	−0.09	−0.02	1																
SLR	0.23	−0.02	0.06	0.27	1															
PUSH	−0.18	0.13	−0.20	−0.18	−0.16	1														
ROT	0.26	0.21	0.09	0.11	0.07	0.06	1													
POS	−0.12	−0.23	−0.12	−0.11	−0.03	−0.20	0.11	1												
SPOS	0.26	0.13	0.32	−0.07	−0.06	0.09	0.14	−0.00	1											
FLEX	0.19	−0.01	0.18	0.04	0.26	−0.02	0.25	−0.03	0.02	1										
EXT	0.23	0.23	0.29	0.10	0.30	0.15	0.10	−0.04	0.13	0.03	1									
BEND	0.08	−0.08	0.03	0.03	0.24	0.04	−0.13	−0.20	0.17	0.20	0.32	1								
TWST	0.33	0.02	0.34	0.20	0.44	−0.18	0.30	0.12	0.23	0.18	0.36	0.25	1							
GAIT	0.01	−0.04	−0.09	−0.24	−0.33	−0.10	0.06	−0.06	−0.10	0.01	−0.04	−0.31	−0.26	1						
BOX	0.39	0.21	0.41	0.28	0.27	0.02	0.23	0.19	0.25	0.15	0.09	−0.18	0.30	−0.31	1					
COIN	0.14	−0.04	0.06	0.19	0.16	0.02	0.20	0.20	0.02	0.22	0.24	0.02	0.08	−0.14	0.18	1				
SLDL	0.15	0.12	0.12	0.07	0.03	−0.40	0.21	0.24	−0.02	0.02	−0.18	−0.13	−0.01	0.05	0.29	−0.22	1			
SLSQ	0.36	0.39	0.39	0.05	0.02	0.03	0.31	0.21	0.23	0.17	0.05	−0.12	0.15	−0.33	0.40	0.04	0.37	1		
TORS	0.28	0.16	0.24	0.07	0.26	−0.17	0.34	−0.01	0.06	0.24	0.30	0.31	0.25	0.09	0.06	0.22	0.11	0.21	1	
PEL	−0.01	0.17	0.19	0.02	0.18	0.03	−0.02	0.09	0.18	0.05	0.38	0.23	0.02	−0.22	0.08	0.09	−0.08	0.07	0.08	1
TOT	0.55	0.41	0.65	0.22	0.44	−0.09	0.37	−0.02	0.32	0.43	0.54	0.33	0.54	−0.26	0.49	0.29	0.18	0.50	0.51	0.35

Notes: SQT, deep squat; HRD, hurdle step; LNG, in-line lunge; SHDR, shoulder mobility; SLR, straight leg raise; PUSH, trunk stability push-up; ROT, rotary stability; POS, standing posture; SPOS, seated posture; FLEX, segmental flexion; EXT, segmental extension; BEND, segmental lateral bend; TEST, segmental twist; GAIT, gait; BOX, box lift; COIN, coin lift; SLDL, single leg deadlift; SLSQ, single leg squat; TORS, torsion control; PEL, pelvis rock; TOT, total movement score. Shaded areas denote significant correlations ($p < 0.05$).

Table 3. Correlations between fitness variables and movement tasks.

	SIT	FPLK	BSE	Right SPLK	Left SPLK	Right GRP	Left GRP	PUP
SQT	−0.12	0.07	0.25	0.19	0.18	−0.24	−0.30	0.01
HRD	0.17	−0.19	−0.13	−0.11	−0.07	0.27	0.16	−0.11
LNG	0.08	0.02	0.02	0.19	0.27	0.03	−0.11	−0.14
SHDR	−0.09	0.11	0.12	0.11	−0.06	0.05	0.05	0.02
SLR	0.11	−0.01	0.34	0.20	0.06	0.03	0.11	0.16
PUSH	0.06	−0.21	−0.20	−0.32	−0.33	0.17	0.12	−0.26
ROT	0.42	−0.10	0.13	0.14	0.00	0.12	0.10	0.17
POS	0.10	0.12	0.20	0.18	0.08	−0.04	−0.08	0.06
SPOS	−0.11	−0.05	0.13	−0.04	0.05	−0.21	−0.27	−0.31
FLEX	0.20	0.05	0.25	0.01	0.00	−0.05	−0.01	−0.01
EXT	0.17	0.07	0.15	0.25	0.22	−0.11	−0.01	−0.10
BEND	0.16	0.09	0.07	0.04	0.07	−0.25	−0.23	−0.11
TWST	0.07	0.08	0.29	0.43	0.31	−0.03	−0.18	0.19
GAIT	−0.08	−0.09	0.09	−0.15	−0.07	−0.12	−0.17	0.06
BOX	0.09	−0.13	0.21	0.06	−0.03	0.13	0.05	−0.02
COIN	0.07	0.09	0.05	0.05	0.01	−0.15	−0.04	−0.10
SLDL	0.23	−0.01	0.13	0.02	−0.05	0.03	−0.16	0.03
SLSQ	0.12	−0.02	0.17	0.06	−0.03	0.13	−0.08	−0.04
TORS	0.18	0.09	0.14	0.32	0.23	−0.20	−0.20	0.08
PEL	0.07	−0.00	0.13	0.05	0.10	0.11	0.20	−0.14
TOT	0.26	0.06	0.33	0.25	0.23	0.02	−0.07	−0.01

Notes: SIT, static sit-up posture; FPLK, front plank; SPLK, side plank; BSE, Beiring-Sorenson extension; GRP, grip strength; PUP, pull-ups; SQT, deep squat; HRD, hurdle step; LNG, in-line lunge; SHDR, shoulder mobility; SLR, straight leg raise; PUSH, trunk stability push-up; ROT, rotary stability; POS, standing posture; SPOS, seated posture; FLEX, segmental flexion; EXT, segmental extension; BEND, segmental lateral bend; TEST, segmental twist; GAIT, gait; BOX, box lift; COIN, coin lift; SLDL, single leg deadlift; SLSQ, single leg squat; TORS, torsion control; PEL, pelvis rock; TOT, total movement score. Shaded areas denote significant correlations ($p < 0.05$).

assess the movement pattern used to perform active hip flexion. Pelvis control was evaluated, though the task score is largely dependent on ROM (i.e. how high was the leg raised). Interestingly, the SLR grade did not correlate with the identical motion tested passively (FEXT, Table 4). Therefore, coordination and motor control likely play a much larger role than is often given credit for. Simply increasing a joint's ROM may not transfer to a complex, whole-body motion if an emphasis is not placed on the individual's movement patterns. Schache et al. (2002) concluded that passive tests (e.g. Thomas test) do not reflect the active ROM used in coordinated movements such as running. More recently, Yuktasir and Kaya (2009) and Moreside (2010) found that six-weeks of stretching, though able to increase ROM, had minimal influence on the way that individuals moved while performing whole-body tasks (i.e. jumping and elliptical training, respectively). Additional work in this area may assist us to better understand the transference of ROM or fitness based training to the performance of coordinated whole-body movements.

The authors' acknowledge the limitations associated with using subjective grading criteria to describe movement quality and establish relationships with fitness and ROM variables; however, such an approach was used to mimic clinical practice. All criteria included have been previously published or discussed with practitioners who incorporate movement-based evaluations in their current practice. Further, the intra- and inter-rater reliability of a movement screen similar to that used in this investigation has been shown to be high (Minick et al. 2010, Frohm et al. in press). Our rater's reliability was not established, but the individual was familiar with each task and only asked to note whether each associated compensatory pattern was present. Grades were assigned post collection by the researchers to improve the consistency of scoring.

In conclusion, it appears that the quality of movement is not solely a function of traditionally utilised markers of fitness such as joint ROM, strength and endurance. Training strategies aimed at improving joint ROM or muscular strength that fail to emphasise the way the individuals move may have little impact on movement quality, and thus injury risk and performance. This implies that training movement is a necessary component of preparing for job or sport related readiness. As a note, this cohort of men was chosen for their employment stability. Our intention is to follow their injury incidence and prevalence as they progress through their working careers to see which variables are protective against injury. It is hypothesised those with better movement quality will have fewer musculoskeletal injuries.

Table 4. Correlations between hip range of motion variables and movement tasks.

	Right FFLX	Left FFLX	Right FEXT	Left FEXT	Right EFLX	Left EFLX	Right EEXT	Left EEXT	Right IROT	Left IROT	Right EROT	Left EROT
SQT	0.26	0.06	0.32	0.38	0.21	0.16	0.24	0.23	−0.18	−0.07	−0.05	−0.10
HRD	0.05	0.07	0.05	−0.09	−0.11	−0.04	0.08	0.02	0.36	0.25	0.24	0.18
LNG	0.21	0.02	0.15	0.04	−0.14	0.01	0.18	0.08	0.13	0.12	0.06	0.08
SHDR	0.07	0.24	−0.04	−0.02	0.10	0.10	0.09	0.02	−0.37	−0.27	0.00	0.07
SLR	0.19	0.26	0.12	0.15	−0.00	−0.09	0.07	−0.03	−0.07	−0.06	0.02	0.07
PUSH	−0.15	−0.18	−0.18	0.02	0.25	0.18	0.21	0.16	0.04	−0.11	0.04	−0.04
ROT	−0.11	0.04	0.01	0.05	−0.03	−0.04	−0.05	−0.08	0.16	0.17	0.15	0.03
POS	−0.25	−0.16	0.08	0.03	0.16	0.13	0.03	0.20	−0.05	0.06	−0.04	−0.05
SPOS	0.20	0.15	0.32	0.37	0.35	0.42	0.47	0.36	0.22	0.12	−0.14	−0.11
FLEX	0.09	0.01	0.14	0.32	0.18	0.08	0.14	0.12	−0.28	−0.15	0.06	0.02
EXT	0.35	0.28	0.32	0.13	0.21	0.19	0.22	0.14	0.14	0.16	0.10	−0.05
BEND	0.44	0.31	0.23	0.10	0.28	0.21	0.34	0.08	0.10	0.00	−0.24	−0.12
TWST	0.17	0.25	0.20	0.16	0.13	0.20	0.17	0.15	0.09	0.09	−0.07	−0.06
GAIT	0.02	0.03	0.09	0.14	−0.19	−0.21	−0.17	−0.15	−0.06	0.09	0.01	−0.07
BOX	−0.18	−0.11	0.12	0.18	0.20	0.31	0.19	0.32	−0.24	−0.02	0.03	−0.04
COIN	0.22	0.08	0.13	0.07	0.38	0.29	0.30	0.22	−0.18	−0.03	0.30	0.24
SLDL	−0.26	−0.07	−0.01	−0.01	−0.04	−0.02	0.05	0.14	−0.02	0.09	−0.15	−0.13
SLSQ	−0.02	0.01	0.16	0.12	0.20	0.12	0.17	0.18	0.10	0.10	0.04	0.01
TORS	0.28	0.16	0.25	0.14	0.03	0.03	0.09	−0.04	0.19	0.22	−0.06	0.02
PEL	0.29	0.10	0.26	−0.00	0.17	0.16	0.12	0.09	0.08	0.06	0.02	0.22
TOTAL	0.32	0.19	0.38	0.25	0.30	0.33	0.32	0.27	0.08	0.15	0.03	0.02

Notes: FFLX, hip flexion (knee flexed); FEXT, hip flexion (knee extended); EFLX, hip extension (knee flexed); EEXT, hip extension (knee extended); IROT, hip internal rotation; EROT, hip external rotation; SQT, deep squat; HRD, hurdle step; LNG, in-line lunge; SHDR, shoulder mobility; SLR, straight leg raise; PUSH, trunk stability push-up; ROT, rotary stability; POS, standing posture; SPOS, seated posture; FLEX, segmental flexion; EXT, segmental extension; BEND, segmental lateral bend; TEST, segmental twist; GAIT, gait; BOX, box lift; COIN, coin lift; SLDL, single leg deadlift; SLSQ, single leg squat; TORS, torsion control; PEL, pelvis rock; TOT, total movement score. Shaded areas denote significant correlations ($p < 0.05$).

Acknowledgements

The authors thank the Natural Sciences and Engineering Research Council of Canada for financial support. Participation of the officers of the Toronto Police Service is also gratefully acknowledged.

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