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Masterclass

# Assessment of movement coordination strategies to inform health of movement and guide retraining interventions

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ABSTRACT

*Introduction:* Exploring characteristics of human movement has long been the focus of clinicians and researchers. Changes in movement coordination strategies have been identified in the presence of pain highlighting the need for assessment in clinical practice. A major development in the understanding of movement related disorders is recognition of individual differences in presentation and consequently the need to tailor interventions based on assessment.

*Purpose:* The purpose of this masterclass is to build a rationale for the clinical assessment of movement coordination strategies, exploring loss of movement choices, coordination variability, and to present a clinical framework for individualised management, including the use of cognitive movement control tests and retraining interventions. An approach for the qualitative rating of movement coordination strategies is presented. A compromised movement system may be one characterised by a lack of ability to access motor abundance and display choice in the use of movement coordination strategies. The identification of lost movement choices revealed during the assessment of movement coordination strategies is proposed as a marker of movement health.

*Implications for practice:* The health of the movement system may be informed by the ability to display choice in movement coordination strategies. There is evidence that restoring these choices has clinical utility and an influence on pain and improved function. This approach seeks to provide individuals with more flexible problem solving, enabled through a movement system that is robust to each unique challenge of function. This assessment framework sits within a bigger clinical reasoning picture for sustained quality of life.

## 1. Introduction

The value of movement is central to the Physical Therapy profession and exploring the varying characteristics of human movement is the focus of clinicians and researchers (Sahrmann, 2002; Hides et al., 2019; Everard et al., 2018; Shield and Bourne, 2018). Exploration of motor control, prevalent in the last 25 years, has led to numerous terms being advocated, for example neuromuscular control, neuromotor control, and core stability, leading to debates over terminology and conceptual explanations in clinical practice, education, and research (Low, 2018). A major development in the understanding of movement related disorders, is recognition of individual differences in presentation and the need to tailor interventions based on assessment (Van Dieen et al., 2019; Falla et al., 2007).

A recent commentary presented key principles of four clinical physical therapy approaches, Movement Systems Approach, Mechanical Diagnosis and Therapy, Motor Control Training, and the Integrated Systems Model (Hides et al., 2019). All approaches incorporated detailed assessment to guide individualised treatment, but elements addressed differed. Although these approaches focussed on the evaluation of movement, they did not explore an individual's ability to display choice in their patterns of movement coordination strategies (Dingenen et al., 2018). The present paper, by two of the authors of Dingenen's Masterclass (Dingenen et al., 2018), will explore the concept of displaying choice in movement coordination strategies and its use in a clinical setting.

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Pain, pathology, compromised function and the many dynamic and interacting factors that may be associated with any presentation, make the management of each patient complex (Bittencourt et al., 2016; Hides et al., 2019). Acknowledging the role movement assessment and retraining may play in the clinical environment, Dingenen et al. (2018) proposed a version of the dynamical systems model, Fig. 1, adapted from Holt et al. (Dingenen et al., 2018; Holt et al., 2010). The model represents human movement as the observable response to opportunities and challenges posed by the continual interaction of what Newell identified as task, environmental and individual constraints (Newell, 1986). Dingenen et al. (2018) emphasised placing a clinical focus on the assessment of the movement emerging from these interactions, described as movement coordination strategies, in contrast to focusing upon any particular constraint, for example pain, myofascial restriction or a pathoanatomical structure (Dingenen et al., 2018). Dingenen et al. (2018) proposed that one aspect of assessing movement coordination strategies was to evaluate loss of movement choices, which has been proposed as a marker of movement health (McNeill and Blandford, 2015). The authors of the present paper have experience in the practical application of these assessment and retraining strategies in clinical and performance environments, and research interests in this subject which are reflected in this Masterclass.

The purpose of this masterclass is to build a rationale for the clinical assessment of movement coordination strategies, exploring loss of movement choices, coordination variability, and present a clinical framework for individualised management, including the use of cognitive movement control tests and retraining interventions. The first part of the masterclass presents the concept of movement coordination strategies, explores movement quality including movement as problem solving, movement variability, movement health and choice in movement. The second part presents a clinical framework to explore loss of movement choices through testing patterns of movement coordination strategies with CMCTs. The assessment procedure is detailed including the neutral training region and single joint and multi-joint testing with practical illustrations. Retraining by restoring movement choices is outlined. Finally, this is placed into a clinical reasoning context.

## 2. Movement coordination strategies

Technological innovations, allowing the capture, interpretation and targeting of kinetic and kinematic measures have had a positive impact on clinical outcomes (Al Attar et al., 2017; King et al., 2018; Worsley et al., 2013). King et al. (2018) and Worsley et al. (2013) used kinematic assessment of a functional task (cutting manoeuvre and arm elevation, respectively) to demonstrate the effectiveness of retraining intervention protocols. However, these papers did not use kinematic measures to steer retraining. Therefore, kinematics were employed as an outcome measure, but not as a means to guide interventions. Whilst the utility of the retraining interventions can be translated into clinical practice, the quantification of movement in clinical environments is challenging because of the associated financial and technical burdens. In addition to showing retraining interventions change kinematic measures, a proof of context case report illustrates that assessment of movement coordination strategies can also inform the direction and effectiveness of individualised retraining programmes (Mottram et al., 2019). King et al. (2018) and Worsley et al. (2013) included the characteristics of movement that meet the description of coordination as defined by Kent (2006) in retraining interventions; i.e. the integration of different body parts during the performance of a specific movement pattern (Kent, 2006). It is apparent that coordination refers to more than this observable change in configuration of body parts (Nordin and Dufek, 2019; Kent, 2006) but also intra and intermuscular activation dynamics (Hug and Tucker, 2017; Hawkes et al., 2019) in addition to consideration of the cognitive and perceptual processes linked to the generation of movement coordination strategies (Newell, 1986; Raisbeck and Yamada, 2019). Therefore, this observable characteristic of movement (coordination) is influenced by multiple elements further supporting the value of evaluating the movement coordination strategy. In the absence of technology, a clinically applicable approach to evaluating movement coordination strategies is presented.

### 2.1. Movement quality

Movement quality has been described as qualitative identification and rating of functional compensations, asymmetries, impairments or efficiency of movement control through transitional (e.g. squats, sit to stand) or dynamic movement (e.g. running, landing, cutting) tasks (Whittaker et al., 2017). Some movement quality protocols seek to rate an individual's patterns of coordinated movement against a predetermined 'template' with observable deviations from this model rated as aberrant/error and requiring correction (Cook et al., 2014; Padua et al., 2011). The Landing Error Scoring System evaluates movement

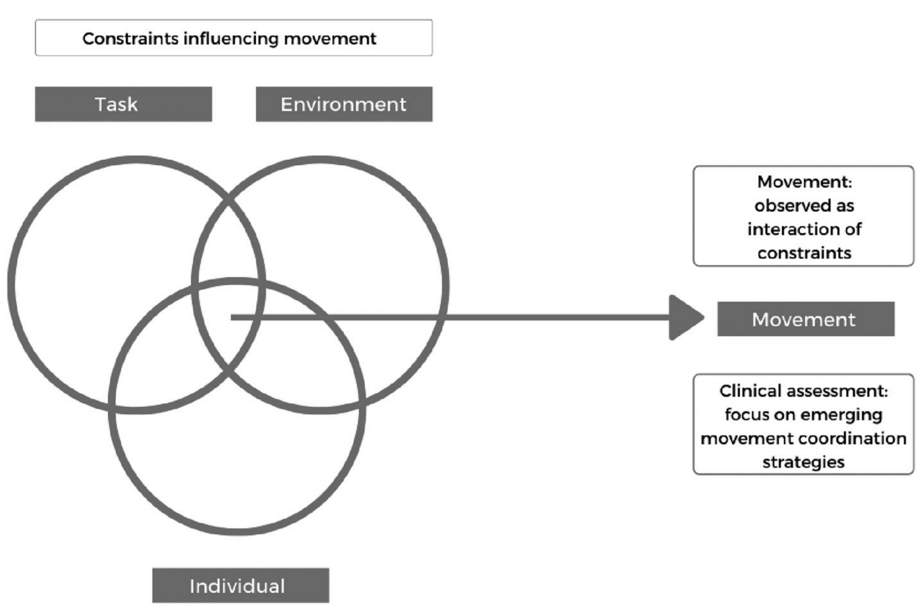


**Fig. 1.** Movement is influenced by an interaction of constraints of the task, individual and environment.

quality during jump-landing and changes in movement quality been associated with anterior cruciate ligament injury (Padua et al., 2015). The movement quality perspective has received criticism, from those questioning whether any movement can be considered aberrant (Guccione et al., 2019). Guccione et al. (2019) suggest the phenomenon of movement represents a problem-solving property, employed by individuals to accommodate the challenges presented by numerous constraints.

#### 2.1.1. Movement as problem solving

A major challenge for qualitative rating of movement as a biomarker is the lack of clear definitions for optimal task performance (Glazier and Mehdizadeh, 2019; Konig et al., 2016). When movement is perceived as a problem-solving phenomenon, it appears individuals solve problems through varying solutions in response to a perpetual state of changing demands between and within constraints to achieve a consistent outcome (Davids et al., 2003; Guccione et al., 2019). Motor redundancy, now reconceptualised as 'motor abundance', supplies the potential for this problem solving, facilitating a consistent task outcome (Bernstein, 1967; Davids et al., 2003; Latash, 2012). Rather than the existence of a single 'optimal' strategy, to respond to changing demands, it appears individuals find a 'good enough' solution (Loeb, 2012). The use of a wide range of solutions may allow the stresses of function to be shared across a range of tissues (Bouillard et al., 2014; Blandford et al., 2018a; James et al., 2014).

Characteristics of movements are seen to change in clinical populations (Hodges and Smeets, 2015), for example changes in kinematics are seen in the presence of pain and injury (Christe et al., 2017; Dingenen et al., 2019). These altered movement coordinated strategies may illustrate altered problem solving and may be linked to specific constraints. Although distinctions between groups are identifiable, there is a lack of consensus as to whether metrics that reach statistical significance possess clinical relevance, and perhaps other characteristics of movement should be explored.

#### 2.1.2. Movement variability

Defined as the variation in motor performance over multiple repetitions of a task (James et al., 2000), movement variability has been explored in clinical presentations including, acute injury and pain (Seay et al., 2011; Weir et al., 2019), overuse injury (Hamill et al., 2012), injury recurrence (Edwards et al., 2017; Davis et al., 2019), pathology (Kawakami et al., 2019) and aging (Hausdorff et al., 2001). Therefore, movement variability is of interest to the clinician. The degree of movement variability may be a marker of a robust movement system, a theme apparent within clinically focussed, coordination variability literature (Davis et al., 2019; Kawakami et al., 2019; Weir et al., 2019). Although these emerging papers are highlighting the importance of considering movement variability, currently there is little direct translation into the clinic in terms of assessment and rehabilitation. Interestingly, Kawakami et al. (2019) observed changes in coordination patterns at the rearfoot and midfoot is associated with forefoot hypermobility in people with hallux valgus, illustrating a mutlisegmental approach is needed in assessment and rehabilitation. Some authors have suggested the existence of an optimal window of variability (Konig et al., 2016; Harbourne and Stergiou, 2009) in which healthy subjects function. Clinical groups illustrate both reduced and increased coordination variability (Madeleine et al., 2008; Hodges and Tucker, 2011). Pain has been associated with increased coordination variability which may indicate a strategy used by people in pain to search for less painful movement patterns (Hodges and Tucker, 2011; Srinivasan and Mathiassen, 2012). Altered proprioception following injury is linked with increased coordination variability (Baida et al., 2018). Reduced coordination variability is suggested to be a risk factor for overuse injury (Nordin and Dufek, 2019; Hamill et al., 2012) but clinically also seen as a solution to minimise pain provoking movement coordination strategies. Coordination variability can be quantified in the laboratory using kinematic measures but is not clinically viable. There are calls for movement variability analysis to extend into routine clinical evaluations (Harbourne and Stergiou, 2009; Needham et al., 2015). This masterclass presents the use of cognitive movement control tests as a qualitative rating to inform on coordination variability by the assessment of movement coordination strategies within a clinical setting.

#### 2.1.3. Movement health and choice in movement

The concept of movement health is defined as 'a state in which the individual is more than just injury free but possesses choice in their movement outcomes' and this is suggested to act as a marker of the current status of the movement system (McNeill and Blandford, 2015). Conceptually, individuals with a more robust state of movement health can sustain the achievement of any desired movement task by accessing the wealth of movement coordination strategies within motor abundance (Dingenen et al., 2018). A compromised movement system may be one characterised by a lack of ability to access motor abundance and display choice in the use of movement coordination strategies. The identification of lost movement choices revealed during the assessment of movement coordination strategies is a marker of movement health.

## 3. Testing patterns of movement coordination strategies/ movement choices

This present masterclass presents a clinical framework to explore loss of movement choices. The protocol demands a cognitive display of a movement task suggested to represent an individual's ability to access what motor abundance supplies, at will. An inability to vary a movement coordination strategy illustrates loss of movement choices. However, as this performance is accompanied by a lack of choice, it would infer the presence of the inflexible problem solving linked to overuse injury (Nordin and Dufek, 2019). Alternatively, an individual's performance that is characterised by both a constant variation in movement coordination strategy, and an inability to cognitively demonstrate precision, appears to represent the high variability associated with compromised neuromuscular regulation of movement (Baida et al., 2018). Rather than suggesting there is an ideal movement coordination strategy, the protocol seeks to reveal whether; i) an individual consistently employs one strategy that is invariant even when provided the opportunity to change or ii) constantly varies strategy but cannot demonstrate consistency in their performance if so required. This possession of choice of movement can be evaluated with cognitive movement control tests (CMCT).

### 3.1. Cognitive movement control tests for assessing patterns of movement coordination strategies

We propose that CMCTs allow for a qualitative rating of coordination variability that can be used to test movement coordination strategies. We put forward the term loss of movement choices (LMC) is used to inform on the inability to vary a movement coordination strategy. CMCTs demand an individual to cognitively coordinate movement at a specific joint or region (site) in a particular plane of movement (direction), under low and high threshold loading during single and multi-joint tests, while producing movement at another joint segment to a benchmark standard (Dingenen et al., 2018; Mischiati et al., 2015; Monnier et al., 2012; Wilson et al., 2018; Mottram and Comerford, 2008; Comerford and Mottram, 2012; Mottram et al., 2019; Botha et al., 2014; Roussel et al., 2009). These CMCTs ultimately seek to reveal what has been described as uncontrolled movement, defined as 'an inability to cognitively control movement at a specific site and direction, while moving elsewhere to benchmark standards' (Comerford and Mottram, 2012). Uncontrolled movement can be considered to represent LMC (loss of movement choices) and can be notated by the Site, Direction, Threshold ®. The site is the region e.g. hip, scapula, the direction is a physiological motion (for example, flexion, extension, rotation) and/or accessory motion (anterior translation), recruitment threshold is low or high (Dingenen et al., 2018; Mischiati et al., 2015). The reality is that it is impossible to prevent movement occurring at any joint or region; however, within clinical practice, an inability to cognitively prevent 'observable' movement at this site is deemed a loss of choice. This notation of Site, Direction and Threshold ® represents a clinical tool allowing loss of choice in movement coordination strategies to be qualified and considered within the bigger picture of clinical reasoning. The CMCTs are not tests of functional performance but are suggested to inform of loss of choice in movement. CMCTs have demonstrated good to excellent inter- and intra-rater reliability (Luomajoki et al., 2007; Mischiati et al., 2015; Rajasekar et al., 2017; Lenzlinger-Asprion et al., 2017; Segarra et al., 2015; Webb et al., 2018; Monnier et al., 2012).

### 3.2. Assessment procedure for cognitive movement control tests

The CMCTs described in the present paper follow clear principles of assessment procedure; a clearly defined start position, end position, and benchmark that must be achieved through the test. Examples include: Arm Flexion Test (Comerford and Mottram, 2012; Mottram, 2003), Kinetic Medial Rotation Test (Morrissey et al., 2008; Comerford and Mottram, 2012; Rajasekar et al., 2017), Small Knee Bend Test (Comerford and Mottram, 2012; Mischiati et al., 2015; Botha et al., 2014), Double Knee Swing Test (Comerford and Mottram, 2012; McNeill, 2014; Mischiati et al., 2015) and Split Squat and Fast Feet Change Test (Mischiati et al., 2015). Details of the principles of test procedures are set out in Table 1.

To set up a CMCT test, the individual is made aware of the required movement with visual, auditory and kinaesthetic cues. An opportunity to practice is provided, and feedback given. To pass the test, the individual must display the ability to consciously maintain the desired alignment at the region of interest (site and direction) whilst the region above or below, or the same joint in a different direction is actively moved to achieve a pre-determined benchmark. For example, Arm Flexion Test (Table 3); limiting observable movement of the site (scapula), whilst moving the glenohumeral joint into 90 degrees of flexion and return without observing scapular downward rotation (direction); or during Kinetic Medial Rotation Test (Table 4) limiting observable movement of glenohumeral joint (site), anterior translation whilst moving the glenohumeral joint into medial rotation.Test performance is observed and evaluated during both the achievement of the benchmark and its return (Mottram and Comerford, 2008; Comerford and Mottram, 2012).

#### 3.2.1. Neutral training region

Testing with CMCTs requires the region of interest to be positioned in a neutral alignment. Fig. 2 represents the possible range the neutral position can sit within the three planes of movement. Rather than equating to 'ideal', the neutral alignment supplies the opportunity for a loss of movement choice to present in any available direction. If testing consistently began with the site of interest at end range, any loss of choice following this motion path would not be observed; low variability in coordination accompanied by a loss of choice would not appear. Additionally, in contrast to end range positions, which facilitate heightened joint sense position (Safran et al., 2001) a greater challenge may be imposed if the neutral alignment is required to be maintained. Such a challenge may then inform the presence of high coordination variability, suggested to accompany diminished proprioception (Baida et al., 2018).

**Table 1**
Cognitive Movement Control Test: Principles of procedure.

| Cognitive Movement Control Test: Procedure | |
|---|---|
| Start position | Neutral training region |
| Teaching the test movement | Teach the test movement with varying strategies:<br>• Visually demonstrate the test's 'shape' and movement<br>• Verbally explain and describe the test movement and use of imagery<br>• Facilitate/guide the person through the test movement |
| Active learning | Practice the movement with facilitation and feedback<br>3-8 repetitions are usually sufficient for facilitation and learning |
| Test | When confident that the person understands the test movement or action, perform the test to the benchmark, without visual or tactile feedback, verbal facilitation, or corrective instruction |
| Rating | On the test procedure, the therapists observe the performance of the test. Any observable uncontrolled movement is notated as site (X) and direction (X) of loss of movement choice |

**Table 2**
Outline of five Cognitive Movement Control Tests.

| Test | Identifies the Site, Direction, Threshold ® of loss of movement choices | Clinical Judgements |
|---|---|---|
| Table 3 (Single Joint) Arm Flexion Test (Comerford and Mottram, 2012; Mottram, 2003) | Site: scapula<br>Direction: downward rotation<br>Threshold: low | • Identifies uncontrolled scapula downward rotation associated with 'impingement type' symptoms (Worsley et al., 2013)<br>• Kinematic differences between individuals noted on the test (Warner et al., 2015) |
| Table 4 (Multi-joint) Kinetic Medial Rotation Test (Comerford and Mottram, 2012) | Site: Scapula<br>Direction: forward tilt<br>Threshold: low<br>Site: glenohumeral joint<br>Direction: anterior<br>Threshold: low | • Useful to identify primary loss of choice of scapula forward tilt or glenohumeral translation (Morrissey et al., 2008)<br>• Reliability, (Rajasekar et al., 2017; Lluch et al., 2014; Mischiati et al., 2015) |
| Table 5 (both single joint and multi-joint) Small Knee Bend Test (Comerford and Mottram, 2012) | Site: hip<br>Direction: flexion<br>Threshold: low | • Clinical utility in academy footballers with femoroacetabular impingement syndrome (Botha et al., 2014)<br>• Reliability (Mischiati et al., 2015) |
| Table 6 (Multi-joint) The Double Knee Swing Test (McNeill, 2014; Comerford and Mottram, 2012) | Site: low back and pelvis<br>Direction: rotation<br>Threshold: low<br>Site: low back and pelvis<br>Direction: side-bend<br>Threshold: low<br>Site: hip<br>Direction: flexion<br>Threshold: low<br>Site: lower leg<br>Direction: lateral rotation<br>Threshold: low<br>Site: foot<br>Direction: eversion<br>Threshold: low | • Identifies primary loss of movement choices at pelvis and leg on a rotary challenge<br>• Clinical utility (Mottram et al., 2019)<br>• Reliability (Mischiati et al., 2015) |
| Table 7 (Multi-joint) Split Squat and Fast Feet Change Test (Mischiati et al., 2015) | Site: low back and pelvis<br>Direction: side-bend<br>Threshold: high<br>Site: hip<br>Direction: flexion<br>Threshold: high<br>Site: hip<br>Direction: medial rotation<br>Threshold: high<br>Site: tibia<br>Direction: lateral rotation<br>Threshold: high<br>Site: foot<br>Direction: inversion<br>Threshold: high | • Identifies primary loss of movement choices at pelvis and leg on a sagittal challenge, with fast movement<br>• Clinical utility (Mottram et al., 2019)<br>• Reliability (Mischiati et al., 2015) |

**Table 3**
Test description CMCT: Arm Flexion.

| Arm Flexion Test | Tests for scapula control (scapular downward rotation) |
|---|---|
| Start position  | Standing, arm resting by side in neutral rotation (palm in), scapula in neutral. Maintain scapula as arm lifts through 90° of shoulder flexion then lower back to side. |
| Test movement  | Move: arm to 90° gleno-humeral joint flexion and return with a neutral humeral rotation (palm in, thumb up) |
| Benchmark: | 90° gleno-humeral flexion – arm horizontal in front |
| Test pass | There is no observable movement of the scapula into downward rotation |
| Presence of loss of movement choice | Observable loss of scapula orientation into downward rotation |

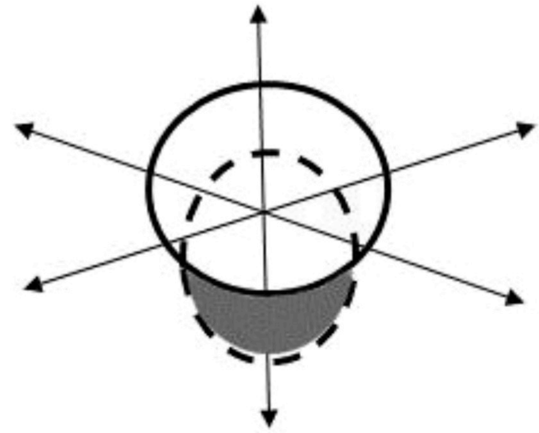

**Fig. 2.** The neutral training region. The solid circle represents the neutral position of a region within three planes of movement. The dotted line illustrates a change in the training region and the shaded area is outside the neutral position at or near the end of range.

### 3.2.2. *Single joint and multi-joint testing*

The protocol for CMCTs can be applied to both single joint and multi-joint testing (Comerford and Mottram, 2012; Mischiati et al., 2015). Single joint tests have been shown to have clinical utility, especially in the management of pain (Worsley et al., 2013; Luomajoki et al., 2008; Mottram et al., 2019). However, it is apparent individuals employ whole body movement coordination strategies, reducing variability at one region whilst increasing it at another (Edwards et al., 2017; Brown et al., 2012). Therefore, multi-joint testing protocols may allow for this dynamic problem-solving to be captured in a more ecologically relevant manner once pain is resolved (Mischiati et al., 2015; Mottram et al., 2019).

**Table 4**
Test description CMCT: Kinetic Medial Rotation Test.

| Kinetic Medial Rotation Test | Tests for scapula control (scapular forward tilt) and glenohumeral control (anterior translation) |
|---|---|
| Start position  | Supine with 90° humeral abduction (hand to ceiling with humerus) in plane of scapula (use to block/towel for support) – palpate coracoid and humeral head |
| Test movement  | Move: arm to 90° gleno-humeral joint medial rotation and return |
| Benchmark: | 60° gleno-humeral medial rotation – arm abducted 90° |
| Test pass | No observable/palpable loss of scapula orientation into forward tilt or glenohumeral joint into anterior translation |
| Presence of loss of movement choice | Observable/palpable loss of scapula orientation into forward tilt or glenohumeral joint into anterior translation |

### 3.2.3. *Practical illustrations of cognitive movement control tests*

Five examples of CMCTs are described in Table 2 and protocols in Tables 3–7. The results of these CMCTs inform retraining priorities. Sites and directions of LMCs related to pain presentations are considered along with those related to performance. As movement represents a dynamic problem-solving phenomenon, these tests can be used to evaluate change over time.

## 4. Restoring movement choices

If failing a test represents an LMC then retraining must be steered to restore this choice. The clinical application of movement retraining interventions, focusing on restoring movement choices, aim to provide the

**Table 5**
Test description CMCT: Single Leg Small Knee Bend.

| Single Leg Small Knee Bend Test | Tests for control of hip flexion |
|---|---|
| Start position  | Stand feet hip width apart with inside borders of feet parallel, stance is upright with upper body vertical, trunk level, neutral pelvis and weight balanced over midfoot. Shift weight onto one foot and lift other foot just clear of the floor. In this single leg stance the 2nd metatarsal is aligned along neutral line (a line that is 10° lateral to the sagittal plane). No lateral deviation, tilt or rotation of the trunk or pelvis. The head, sternum and pubic symphysis should be vertically aligned above the inside edge of the stance foot with the shoulders level. The trunk is upright |
| Test movement  | Perform small knee bend, by flexing knee and dorsiflexing ankle, keeping heel on floor (body weight on heel not ball of foot). Line of femur ideally remains on the 10° 'neutral line' (knees out over 2nd toe. Trunk stays vertical |
| Benchmark: | Knee flexion to 3–8 cm past toes with trunk upright |
| Test pass | No observable movement of hip into flexion (trunk lean) |
| Presence of loss of movement choice | Observable loss of hip into flexion (trunk lean) |

**Table 6**
Test description CMCT: The Double Knee Swing Test.

| The Double Knee Swing Test | Tests for control of low back and pelvis rotation, low back and pelvis side-bend, hip flexion, lower leg lateral rotation, foot eversion |
|---|---|
| Start position  | Stand with the feet under hips (10–15 cms apart). Inside edges of the feet parallel and aligned straight ahead. Keeping heels down and trunk upright, bend the knees and lower the hips into a ¼ squat position until the knees are flexed approximately 5 cm in front of toes, with the thighs aligned out over the second toe (Small Knee Bend position). The back should be straight and vertical as if sliding down a wall |
| Test movement  | Swing both legs simultaneously to the left and then right to 20° range of hip rotation (E.g. as the knees swing to the (L), the (L) hip should laterally rotate to 20° away from the midline and the (R) hip should simultaneously medially rotate 20° across the midline. The pelvis should not rotate or laterally shift to follow the knees. As the knees swing side to side, allow the feet to roll and shift weight from the inside edge (pronation) to the outside edge (supination). As the knee swings out into lateral rotation, do not allow the foot to invert. Keep the 1st metatarsal head (base of the big toe) fully weight bearing on the floor. Do not allow it to unload or lift off |
| Benchmark: | The range of knee swing with both knees moving simultaneously should be 20° to each side |
| Test pass | No observable movement of low back and pelvis rotation, low back and pelvis side-bend, hip flexion, lower leg lateral rotation, foot eversion |
| Presence of loss of movement choice | Observable movement of low back and pelvis rotation, low back and pelvis side-bend, hip flexion, lower leg lateral rotation, foot eversion |

**Table 7**
Test description: Split Squat and Fast Feet Change.

| Split Squat and Fast Feet Change | Tests for control of low back and pelvis side-bend, hip flexion, hip medial rotation, tibia lateral rotation, foot inversion |
|---|---|
| Start position  | Step out with one foot (4 foot length), feet facing forwards and arms folded across chest. Keeping the trunk upright, drop down into a lunge. |
| Test movement  | Rapidly switch feet in a split squat movement, control the landing. Then lift the heel of the front foot to full plantarflexion and hold this heel lift in the deep lunge for 5 s, then lower the heel and without straightening up, rapidly switch feet in a split squat movement, control the landing After the landing, again lift the heel of the front foot to full plantarflexion and hold this heel lift in the deep lunge for 5 s. Repeat the heel lift twice with each leg in the forward position |
| Benchmark: | Deep lunge (4 x foot length) with heel lift (5 s hold) and rapid split squat (x 4 reps) |
| Test pass | Minor deviations in body alignment but followed by a rapid restoration of original alignment in low back and pelvis side-bend, hip flexion, hip medial rotation, tibia lateral rotation, foot inversion |
| Presence of loss of movement choice | Large amplitudes of movement in any of the following sites and directions or an inability to immediately restore original body alignment; low back and pelvis side-bend, hip flexion, hip medial rotation, tibia lateral rotation, foot inversion. Oscillating in any plane constitutes a fail |

individual with the ability to access the wealth of potential present within motor abundance; giving individuals more 'ways' to achieve movement outcomes. Retraining movement coordination strategies demands observable movement to be controlled whilst moving elsewhere. Such cognitively and biomechanically constrained patterns of coordination rarely appear during function. However, this intervention seeks to restore choice in the building blocks of coordination, required for more complex movement coordination strategies. Movement coordination strategy retraining interventions cannot be considered to be the end goal of this individual's journey but do represent a stepping stone on this path.

### 4.1. *Strategies to restore movement choices*

The fundamental aim of movement retraining interventions is to transition individuals towards a more robust state of movement health. This is illustrated in Fig. 3. Some considerations for restoring movement choices with cognitive movement control retraining are detailed in Table 8, and strategies and illustrations previously described (Mottram and Comerford, 2008; Mottram et al., 2019; Worsley et al., 2013).

The movement retraining intervention is informed by identifying the site, direction and threshold ® of LMC and a clinical reasoning process to match priorities to client's goals. For example, a goal may be to manage pain and local tissue stress by sharing the demands of function across a range of tissues or restore movement choices for improved performance. The process of retraining movement coordination strategies has been shown to have clinical utility at the shoulder (Worsley et al., 2013; Struyf et al., 2013) and hip and groin (Wilson et al., 2018; Mottram et al., 2019). These papers support proof of concept of this approach, however more robust evidence is required. A systematic review and

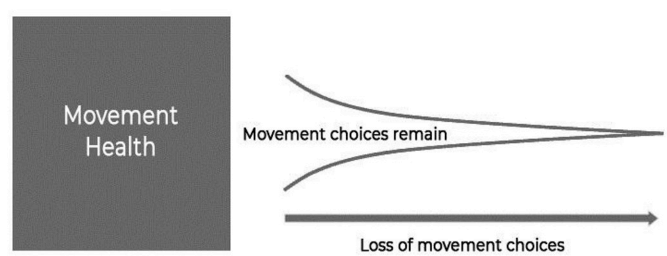


**Fig. 3.** This figure is a conceptualised representation of how movement choices may be lost. The aim of retraining is to restore movement choices. (Reproduced with permission of Comera Movement Science).

meta-analysis of eleven publications in 2018 explored the effectiveness of movement control exercises, on patients with non-specific low back pain and movement control impairments (Luomajoki et al., 2018). There was low to moderate quality evidence, suggesting a positive effect of movement control exercises on disability and pain severity, in the short-term and long-term, in nonspecific low back pain. Clearly, further high quality RCT's are required into the effectiveness of this approach. However, eligibility criteria must include the presence of LCMs. The present authors propose using CMCTs to identify the presence of LCMs can be used to stratify patients likely to respond to retraining. This approach empowers people to restore choice in movement (access motor abundance) and sits within the bigger clinical reasoning picture.

**Table 8**
Considerations for restoring loss of movement choices with cognitive movement control retraining.

| Considerations for Restoring Movement Choices with Cognitive Movement Control Retraining |
| --- |
| Restoring Loss of Movement Choices (LMC) |
| The person is taught to move an adjacent joint above or below in the same direction as the loss of movement choice (LMC), or same joint (in a different direction of the LMC) only as far as: |
| • movement is independent of the LMC |
| • control can be maintained at the site of the LMC |
| • any joint or myofascial restriction permits |
| Facilitation |
| Feedback tools can be employed to teach and facilitate the restoration of choice in coordination |
| • visual feedback (watch the movement) |
| • visualisation (including imagery) |
| • palpation feedback (with the person's own hands) |
| • kinaesthetic feedback (with adhesive tape and skin tension) |
| • verbal instruction and verbal correction, and motion monitoring equipment (e.g. pressure biofeedback) |
| • the body or limb weight may be unloaded (supported) |
| • proprioceptive input |
| • encourage normal breathing patterns |
| • the person should regain awareness of alignment, movement precision, muscle tension and effort, the sensation of 'easy' patterning, multi-joint motion differences |
| Repetition |
| Slow, low effort repetitions of the movement pattern are required |
| • practise until it feels familiar and natural |
| • numerous repetitions are required to elicit change in the patterns of coordination |
| • a general guide is to perform 20–30 or up to 2 min, of slow repetitions x 2 day (Worsley et al., 2013) |
| • supplying structure to this volume of work to be performed to increase engagement (Newell and Verhoeven, 2017) |
| • the retraining interventions should produce or provoke any symptoms |
| 'Time under attention' (McNeill and Blandford, 2015), active, cognitive engagement with the movement task performed |
| • mindful movement and requires cognitive retraining |
| • tasks are not so easy that they fail to stimulate focused attention, nor so difficult that continuous failure undermines motivation (Kiely, 2017) |
| Progression |
| Challenging the ability to display choice in movement is essential in a progressive programme and can be facilitated by: |
| • reducing load facilitation (unloading) |
| • adding a proprioceptive challenge to the base of support |
| • incorporating an 'unstable' base e.g. balance boards, discs, Pilates reformer, gym balls and other small equipment |
| • retraining progressed into task-specific situations to meet the demands of function |
| • cognitive loading (cognitive loading) (Burcal et al., 2019) |
| • mindful movement practices e.g. Garuda, Pilates, Tai Chi, Yoga, Feldenkrais |
| Motor Learning |
| Three progressive phases of learning (Fitts and Posner, 1967) |
| • cognitive phase, understanding of the required action |
| • associative phase, practice of the programme learned in the cognitive phase |
| • autonomous phase, during which the performer learns to carry out the skill with little conscious effort |
| • cognitive input in the early stages of motor learning, and simple, single plane movement patterns can help shape the pattern |
| Learning transfer and retention |
| • restoration of the ability to display choice in the specific sites and directions considered to be most germane to the patient's presentation is fundamental to this approach; ideally, these restored movement choices augment individuals' problem -solving repertoire, remaining accessible in the presence of imposed demands |
| • no one approach to facilitating transfer into function is likely to prove successful for all patients (Newell and Verhoeven, 2017) a range of strategies is required |
| • consider the use of analogies (Andy et al., 2017) (for example, 'smiling clavicles' to aid restoration of choice associated to inability to prevent downward rotation of the scapula) |
| • motivation is key to transfer (Pugh and Bergin, 2006; Gokeler et al., 2019) the intervention must be strongly connected to the achievement of a change in state that possesses value to the individual |
| Adherence & Education |
| Facilitate adherence |
| • consideration of an agreement between patient and therapist on shared view of management plan, including initial, ongoing and maintenance programmes considering patient preferences |
| • behaviour goal setting – agree a contract with patient that they will do exercises to achieve desired outcome in terms of movement retraining |
| • explore the individuals understanding, beliefs and expectations |
| Education in value of restoring loss of movement choices |
| • gaining insight into link between LMC, presentation and goals and why it will help recurrence |
| • understanding how the site and direction of LMC relates to pain provocation - gaining cognitive awareness of how movement can influence pain |
| • develop an understanding of retraining movement strategy and why it will help symptoms and recurrence |
| • be mindful of the time scale, repetitions and progressions required to invoke change |
| • allow person to demonstrate an ability to perform the retraining movement strategy – help them learn to judge when they are controlling the LMC |

## 5. Clinical reasoning

This paper champions 'movement' as the primary means of intervention to manage pain, limit its recurrence and enhance quality of life. Ultimately, these interventions seek to move individuals towards a sustained, robust state of movement health, by restoring movement choices. However, this process will be optimised if it fits within a person-centred approach, which considers the influence of multiple constraints on any movement coordination strategy.

A multi-dimensional, individual-centred, clinical reasoning framework is proposed based on the consideration of the numerous factors influencing movement choices including:

1. Evaluation of Movement Health, in terms of Site, Direction, Threshold ® of loss of choices in movement
2. Evaluation of syndrome, pathology, clinical signs and imaging findings
3. Consideration of pain mechanism
4. Consideration of any other individual, environmental and task constraints (Comerford and Mottram, 2012) (Fig. 4).

The interactions of these elements will drive the priorities of clinical interventions. Fig. 5 illustrates a model for consideration of assessing and restoring LMC. At the centre of this pathway is the status of an individual's movement health.

Movement health is constantly in a state of flux in response to the influence of numerous constraints. Despite the ever-changing influence of constraints, maintaining movement health across the lifespan may facilitate an individual's progress towards their highest attainable standard of health. Empowering individuals to consider the relationship between life goals, their status of movement health and a sense of how

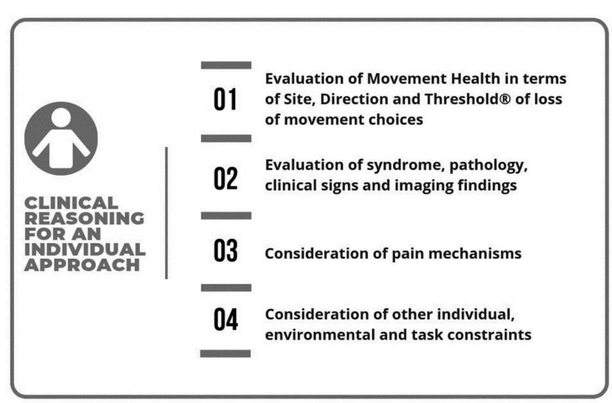


**Fig. 4.** A clinical reasoning framework based on four key factors influencing movement choices (Reproduced with permission of Comera Movement Science).

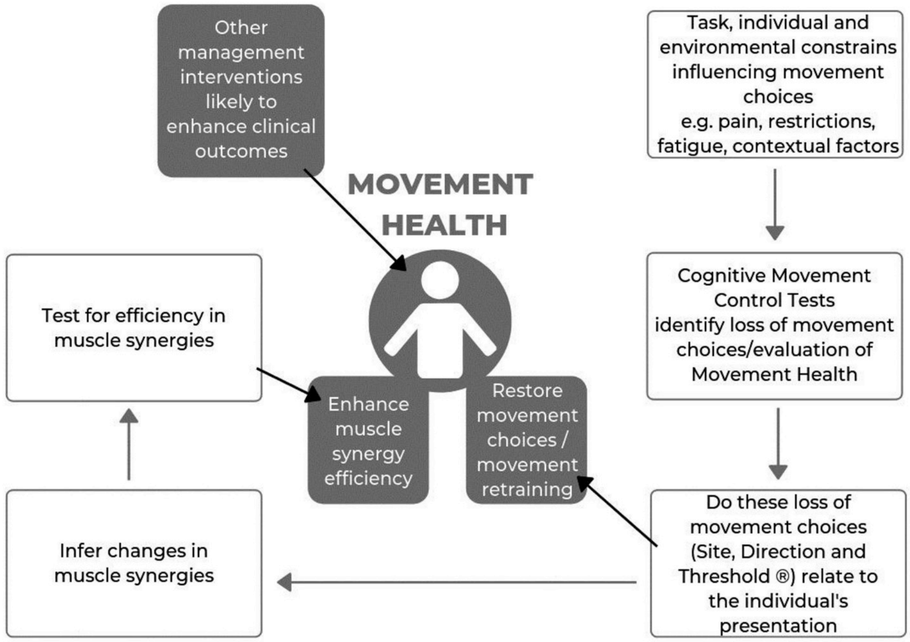


**Fig. 5.** The assessment and retraining of loss of movement choices within a clinical reasoning framework (Reproduced with permission of Comera Movement Science).

their efforts to improve this property can influence their life outcomes, is central to the movement health concept.

Numerous other therapeutic and educational interventions can positively influence movement choices, for example, manual therapy, soft tissue and fascial approaches, pain neuroscience education and cognitive behavioural approaches. The CMCT system can be utilised as an outcome measure to track progression (Mottram et al., 2019).

### 5.1. *Interpreting muscle synergies*

Muscle synergy characteristics have been shown to change in the presence and history of pain (Blandford et al., 2018b; Feeney et al., 2018; Liew et al., 2018). These changes are accompanied by alterations in joint coordination in the lower extremity (Kim et al., 2019). In the shoulder, Worsley et al. observed that scapular downward rotation in individuals with shoulder pain was accompanied by changes in recruitment of serratus anterior and lower trapezius (Worsley et al., 2013). The consistent patterns of movement coordination strategies employed by these individuals on arm elevation, was characterised by more downward rotation than in pain-free individuals. Following retraining these individuals appeared to employ movement coordination strategies as used by those in a more robust state of movement health. There is promising clinical support for the assessment of movement coordination strategies to infer upon relevant changes in muscle synergies. The clinical framework in Fig. 5 includes the consideration of altered muscle behaviour to support clinical decision making. Once the site and direction of LMC has been established, the associated muscle synergies can be explored in respect to movement health. This is an emerging area if interest to the researcher and clinician (Liew et al., 2018; Kim et al., 2019; Mehrabi et al., 2019).

## 6. Summary

The health of the movement system may be informed by the ability to display choice in movement, accessing the wealth of movement coordination strategies afforded by motor abundance. An assessment framework for evaluating patterns of movement coordination strategies is detailed with CMCTs. Restoration of movement choices identified as lost on testing are explored through cognitive movement control retraining interventions. Sitting along-side other interventions, this approach supports sustained, robust problem solving to facilitate enhanced quality of life across the lifespan.

## 7. Conclusion

This Masterclass sets out a perspective on how movement and its problem-solving capacity can be assessed and modified in the clinical setting. For clinicians wishing to adopt a movement-based approach, the identification of LMC may contribute to the clinical reasoning process. Proof of concept of this perspective has been outlined, and clearly further research is needed to improve the quality of evidence to support this approach.

## Ethical approval

Not applicable.

## Funding

None.

## Declaration of competing interest

Sarah Mottram and Lincoln Blandford are employees of Comera Movement Science Ltd, which educates and trains sports, health and fitness professionals to better understand, reduce and manage musculoskeletal injury and pain that can impair movement and compromise performance in their patients, players and clients.

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