

LITERATURE REVIEW

DEVELOPMENT OF PHYSICAL LITERACY AND MOVEMENT COMPETENCY: A LITERATURE REVIEW

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ABSTRACT

Physical literacy was established to explain the knowledge and competence children ideally demonstrate for lifelong health and wellness. Current physical literacy assessment is quantified by how well a child performs fundamental movement skills which include a static balance, vertical jump, sprint, catch, hop, leap, side gallop, kick, skip, strike, throw and dodge.

Fundamental movement skills are included in physical literacy and physical education programs because of documented associations to lifelong participation in physical activity, health benefits and sporting success. However the available evidence is less clear about the underlying causes contributing to the decline in skill proficiency observed in school children.

Foundation movements have been proposed to assess movement capabilities and possible deficiencies in youth and include a squat, lunge, push, pull, hinge, brace and rotation. Foundation movements are naturally developed during infancy. Foundation movements appear to have movement and biomechanical similarities to specific sport skills, recreational activities or activities of daily living. However currently there has been no rigorous research to support foundation movement's efficacy as a screening tool. Whilst research into foundation movements is apparent, focus is placed on the associated fitness related outcomes, quantifying load or muscular strength, exercise prescription for the adult population, or the authors have not provided a description of movement criteria.

The significance of the squat, lunge, push, pull, hinge, brace and rotation are described, evidence for each technique is synthesized and the relationship to fundamental movement skills is analysed. The purpose of this paper was to evaluate the relationship that foundation movements have with fundamental movement skills. The literature review highlights a need for a preliminary assessment of physical competence appropriate for all populations.

Keywords: Foundation movements, fundamental movement skills, physical education, physical literacy

INTRODUCTION

The concept of physical literacy was founded in 2001 to aid the global obesity and sedentary crisis clouding the developed world ¹⁻⁵. Requirements of physical literacy, sports performance and physical education are thought to be underpinned by fundamental sports skill ability ⁶⁻⁹. Fundamental sports skills include locomotion and object control skills such as running, hopping, skipping, throwing, catching and kicking ¹⁰.

Associations to lifelong participation in physical activity, health benefits and sporting success warrant fundamental sports skills inclusion in physical education and physical literacy ¹¹⁻¹⁴. Despite global attention, an overall decline in children's skill performance has been observed and youth obesity, physical inactivity and sedentary lifestyles continue ^{13, 15-17}.

Fundamental sport skill deficiency is continually attributed to inactivity ¹³; however no one has considered the underlying causes contributing to the declining skill proficiency in school children. Giles ¹⁸ argues that foundation movement competencies including a squat, lunge, push, pull, hinge, brace and rotation are more important than skills training. Whilst foundation movements appear to develop naturally and impact fundamental sport skill acquisition, literature is yet to support this claim. This study evaluates the relationship that foundation movements have with fundamental sports skills. The literature review highlights a need for a preliminary assessment of physical competence appropriate for all populations.

BACKGROUND

Physical literacy was established to explain the knowledge and competence children ideally demonstrate for lifelong health and wellness. Associated characteristics of a physically literate individual include competent movement within different environments and contexts, ability to utilise personal movement potential, motivation and confidence to participate in lifelong habitual exercise and thoughtful nutrition ^{5, 19, 20}.

Fundamental movement skills are considered the

determinant of a child's motor abilities and physical literacy. The New South Wales primary school physical education module titled 'Get skilled: Get active' defines a fundamental movement skill as

"an organised series of basic movements that involve the combination of movement patterns of two or more body segments." p.58 ¹⁰.

Skills outlined in the curriculum include a static balance, vertical jump, sprint, catch, hop, leap, side gallop, kick, skip, strike, throw and dodge. Larsson and Quennerstedt ²¹ consider fundamental movement skills to be understood as fundamental sports skills because they do not relate to fundamental day-to-day movements but rather skills needed to perform adequately during sporting pursuits. For the purpose of this review this skill set will be referred to as 'fundamental sports skills'.

Physical education and physical literacy promote fundamental sports skills because of associations between skill proficiency and lifelong healthy practices ^{12, 14, 21}. Physiological, psychological and behavioural development of children, improved physical literacy and long term active lifestyles are attributed to fundamental sport skill proficiency ^{7, 12-14, 21}. Other benefits include optimal body mass index, higher cardio respiratory fitness, and improved perceived physical competence ^{11, 14}. Additionally as children get older, they reduce the amount of time spent being active ^{12, 22-24}. Research has advocated that competent fundamental sport skills can combat dropout during crucial transition periods cited as commencement of formal schooling (5-6 years old), primary to high school (12-13 years old) and school to higher education or the workforce (17-18 years onwards) ²⁵.

Frequent physical activity participation relies on proficiency in fundamental sports skills and in turn allows exposure to characteristics of physical literacy ⁷. Barnett et al. ²⁶ demonstrated that perceived motor ability as a primary school child is a key predictor of physical activity participation as an adolescent. These studies suggest poor development of fundamental sports skills will limit improvements in physical literacy and hinder participation in habitual physical activity.

Physical education goals are well defined and aim

to improve a child's movement ability and confidence to support a physically active, fulfilling lifestyle ¹⁰. Physical literacy is an evolving concept in Australia and yet to be incorporated into the curriculum. The Australian Council for Health, Physical Education and Recreation recommend physical literacy be integrated into the curriculum to provide a balance between health related concepts and movement competence ²⁷. A recent report by the University of Canberra suggests physical literacy interventions should focus on a range of physical activities including transport and play. However, fundamental sports skill proficiency, already utilised in the physical education curriculum is highlighted as the main requirement for establishing physical literacy ²⁸. Therefore the curriculum and physical literacy is susceptible to criticism due to its focus on developing sports skills instead of encouraging holistic movement for all children ²⁹.

Fundamental sports skills are an important component of youth athletic development and recreational physical activity, therefore their place in the curriculum and physical literacy is warranted. However physical literacy is an instrument to understand all human movements and placing primary focus on skills required for sport is narrowing the scope of the concept to sports potential only ²¹. Consequently, defining physical literacy solely by fundamental sports skills performance may be ignoring several characteristics of the concept.

CURRENT PHYSICAL EDUCATION AND PHYSICAL LITERACY ASSESSMENT

Numerous authors have highlighted a distinct gap in the literature; namely the inability to quantify physical literacy of individuals and groups ³⁰⁻³². The original theorist behind physical literacy, Whitehead ²⁰ emphasises that programming must incorporate assessment for learning, but provides no practical application or methods to address

this. Measurability is crucial if physical literacy is to become a key outcome of physical activity experiences ³². Documenting physical literacy measurements aid resource allocation, motivate teachers to provide quality physical education, encourage children's participation in physical activity, evaluate physical education quality and improve the breadth of current physical education assessments ^{32, 33}.

Researchers have attempted to quantify physical literacy; however measurements available are based upon opinion and self-assessment of fundamental sports skills ^{32, 34, 35}. McKean ³¹ suggests to improve our understanding of assessment, researchers need to ascertain performance indicators for movement competencies that underpin physical literacy. Physical literacy assessments available test fundamental sports skills, agility, coordination and balance in a variety of environments ³⁶. Unfortunately due to the focus on sports skill assessment, children with less than optimal movement abilities could go unnoticed.

Fields such as occupational therapy use movement, skill and developmental assessments to detect movement disorders. Ulrich's ³⁷ Test of Gross Motor Development-2 or Henderson and Sugden's (quoted in ¹⁴) Movement Assessment Battery for Children are considered the gold standard in detecting such disorders in children. Movement disorders are diagnosed according to the child's ability in fundamental sports skills. Whilst tests of this nature assess components of each skill, Cools et al. ³⁸ warn that caution needs to be applied when judging a child solely on these results. The reason a child performed that way is overlooked in the results and interventions only focus on weak skill criterion of a particular sports skill ³⁸. Therefore tests of motor development may be missing a key element in their intervention strategy, recognising movement components that underpin skill weaknesses. In addition tests of this nature are only validated for particular populations categorised by age. For example

the Test of Gross Motor Development-2 is validated for young children three to 10 years of age ³⁷.

Within skill acquisition, breaking down a fundamental sport skill into movement components has been established. Pioneering research by Fleishman ³⁹ compartmentalised motor skills into abilities required for successful skill delivery. Speed of movement, reaction time, manual dexterity, aim, multi-limb coordination and control precision are abilities considered ³⁹. For example, for an overarm throw multi-limb coordination, speed of arm movement and aim are specific abilities required for success. Additionally Magill ⁴⁰ described supporting movements for motor skills as behavioural characteristics of the head, body and limbs. He recognises a variety of movements could be adopted to reach a common outcome. For example, movements performed to throw a ball may differ between individuals but reach the same objective ⁴⁰. The thrower could adopt an overarm, underarm or windmill action. Different throwing characteristics between individuals could be attributed to physical features that limit or enhance skill performance ⁴⁰. Whilst Magill ⁴⁰ refer to these characteristics as movements, he categorises movements according to kinetic and kinematic variables such as velocity, displacement, joint angle, torque or electromyographical characteristics. Foundation movement assessment observes how an individual uses their available range of motion and gross motor control within a movement pattern. Neither Fleishman's ³⁹ nor Magill's ⁴⁰ assessment used to describe and quantify the movements that underpin motor skills fall within the scope of foundation movements as they are methods of describing movement variables as opposed to the control of movement.

LIMITATIONS OF AN EXCLUSIVE SKILLS BASED APPROACH TO PHYSICAL LITERACY AND PHYSICAL EDUCATION ASSESSMENT

Children with movement deficiencies are overlooked

Current aims and objectives of physical education and physical literacy overlook children who are unable to produce requirements of fundamental sports skills. Hardy et al. ¹³ acknowledge the strength of 'Get skilled: Get active' assessments process oriented criteria, meaning that the child's movement within the skill is observed as opposed to the outcome of that skill. For example, a child's ability to drive their arms in opposition to their legs is observed during the sprint run, instead of speed. However, Larrson and Quennerstedt ²¹ recognise fundamental sports skill tests aim to mirror the physical movements of children but question how 'fundamental' these skill sets are. The authors deduce that such tests screen how children perform skills but disregard why a child performs that way ²¹. Similarly Cook et al. ⁴¹ illustrate that performance tests fail to evaluate the efficiency by which an individual performs the skill. Little attention is given to movement deficits which potentially predispose an individual to injury and limit performance development ⁴¹.

Children who require more attention due to fundamental sports skill deficiencies are encouraged to practice the under developed component of the skill during active play, participation in organised games and sports, when in fact movement deficits may need consideration ¹³. McKean ³¹ proposes further research into underpinning movements required for fundamental sports skills need to be justified within the literature.

Requirements of physical literacy are unfulfilled

Physical literacy educates participants about using their bodies in different contexts such as for

transport or communication. This process invites them to use their movement vocabulary stored in their memory to move in different environments such as in the water or on ice ^{7, 20, 42-44}. To be physically literate is to understand and respect the physicality of embodiment, to be motivated to use one's own embodied potential to achieve a specified purpose, and to be capable of doing so throughout the lifespan ⁵⁵. Achieving physical literacy allows an individual to explain and analyse essential qualities that improve their movement and can attend to sensations felt during movement ^{5, 20, 42, 43, 45}.

Developing and maintaining physical literacy will not only enhance an individual's quality of life but it may promote healthy living practices to family, friends and associates ^{5, 20, 46}. If a child cannot demonstrate components of a skill such as their throwing arm following through across the body in an overarm throw, they are labelled physically illiterate ^{29, 35}. Whilst fundamental sports skill tests are accurate for sports performance, how does an overarm throw, kick or strike underpin characteristics required for accomplished physical literacy evident in their natural movements during play, transport, interacting with the environment or using their motile capabilities as a means of communication? Current physical literacy research fails to relate fundamental sports skills to all components required for physical literacy.

Sport and physical education objectives amalgamate

Over time physical education aims and objectives have shifted to sport and elite development focus ⁴⁷. This has caused a change in attitude from participatory teaching working towards physically literate individuals to privileging skill, competition and winning ⁴⁷. Sheehan and Katz ⁹ and Coates ⁴⁴ identify competition and team games as the premise underlying most childhood leisure time activities and physical education. Obese children and those with motor skill difficulties tend to avoid physical activity and games both in and out of school as a coping strategy due to poor self-efficacy ^{9, 11, 32, 48}. Frustration and fear of failure within competitive environments is a major determinant of physical

activity avoidance in some children and therefore a major contributor to physical illiteracy ⁹.

Gender Bias

Gender differences in skill proficiency could in fact reflect a gender bias in the nature of fundamental sports skills assessed ¹³. Traditionally boys are more likely to be involved in sports such as cricket and soccer ⁴⁹, therefore the likelihood that they will excel in overarm throw and kick assessments is high ¹³. Conversely, girls are continuously considered less proficient in motor ability when compared to boys ^{50, 51}. However due to their enhanced hamstring flexibility, improved lumbar mobility and hip flexion, girls may excel in movements such as a lunge ⁵².

PRELIMINARY ASSESSMENT

Assessors need to realise that similar human movements occur in a variety of athletic activities ⁴¹. Movement deficiencies are commonly overlooked in the asymptomatic population ⁴¹. Therefore movement assessment is necessary to enhance individuals skills required for athletic pursuits and play ⁴¹. Basic movement patterns need to be assessed to identify areas of movement that could lead to injury or performance barriers ⁶². Cook et al. ⁴¹ argue that movement competencies such as a lunge, should be evaluated during pre-season to assess which athletes possess or lack the ability to perform essential movements required for sports performance. Similarly movement competencies should be analysed annually for the whole school population to assess which children have the required movement abilities to succeed in physical education, sport and recreational physical activity.

Practitioners rarely assess movement abilities, preferring to focus on performance indicators such as speed or distance ⁴¹. Progression of sports specific skills may be restricted by poor development of basic movement competencies, meaning individuals will progress to a point where they are limited by their movement abilities ⁵³. No studies have analysed the importance of

underpinning movements involved in fundamental sports skills and the possible relationship to elite athletic development or physical activity participation.

To improve all characteristics associated with physical literacy and influence lifelong healthy behaviours, a preliminary assessment is required that can be practiced across all populations free from age, skill level and gender bias. The significance of a movement assessment approach to physical literacy is yet to be explored in the literature. Further investigation is warranted to understand the role movements have in fundamental sports skill success

SUMMARY

Physical literacy explains the knowledge and competence humans need for lifelong health and wellness. In Australia, Physical Literacy is gaining awareness, but is yet to be adopted into the national education curriculum. Current definitions and interventions focus on fundamental sports skills as the definitive achievement of physical literacy. The New South Wales physical education curriculum titled 'Get skilled: Get active' was integrated into the curriculum due to fundamental sports skills innate relationship with positive health behaviours and lifelong habitual physical activity. Whilst this skill set is crucial for sports development and talent identification, concern has been raised at the specific competitive sport and games nature that fundamental sports skills promote. Unskilled children are likely to withdraw and avoid movement opportunities of this nature. Consequently unskilled populations are labelled as physically illiterate. Furthermore fundamental sports skills do not support all characteristics required to attain physical literacy. Therefore it is necessary to investigate whether movement competencies underpin fundamental sports skills as a preliminary assessment for physical education and physical literacy.

MOVEMENT DYNAMICS

Youth athletic development practitioner, Kelvin Giles¹⁸ developed a screening method called 'Movement Dynamics'. Alleged to assess movement capabilities and possible deficiencies in youth, Giles concentrates on seven foundation movements including a squat, lunge, push, pull, hinge, brace and rotation¹⁸. The aim of assessing these movements is to understand the individuals required level of training in a wide range of movements. Giles draws upon relationships between movement planes, movement types and movement outcomes to explain movement success. For example, the squat, an assessment of bi-lateral movement assesses triple flexion – extension of the hip, knee and ankle. Triple flexion-extension has a close relationship to joint mechanics in walking, running, jumping, change of direction and change of speed skills required for daily activity and sport¹⁸.

Motor development is influenced by exposure to movement demands, adequate instruction, social and genetic factors⁵⁴. Foundation movements are naturally developed during infancy with most movements reaching maturity around five to seven years⁵³. Motor control should improve with age, however some children and indeed adults will never progress past the elementary stage of fundamental sports skills because of negligible instruction, practice, encouragement and feedback^{53,54}.

Giles has performed foundation movement assessments with elite and recreational athletes for over 20 years which led him to developing the screening tool for children. However, foundation movement competencies used to objectively quantify physical literacy by Giles have yet to be linked with movement requirements of fundamental sports skills. Results from screening present the assessor with individual movement capabilities and deficiencies for the purpose of movement enhancement programming¹⁸. Therefore results of foundation movement assessment could address the continuing decline in fundamental sports skill competency observed by Hardy et al.¹³. Pinpointing movement inefficiencies and applying relevant interventions could encourage increased physical activity participation and enhanced sports performance.

FOUNDATION MOVEMENT COMPETENCIES

There appears to be sound logic to foundation movements, such as movement and biomechanical similarities to specific sport skills or activities of daily living. Table 1 presents foundation movements and related fundamental sports skills, movements for play and activities of daily living. However the weakness lies in the lack of scientific evidence supporting the importance of these movements to the currently accepted definition of physical literacy. Whilst literature provides supporting evidence for the benefits of developing these movement capacities in adults ⁵⁵⁻⁵⁷, children are not “mini adults” owing to their unique levels of growth, maturation and stature ^{22, 58}. Physical and neurological immaturity contributes to less refined and inconsistent movement patterns observed in children compared to adults. For example, compared to older children and adults, infants utilise a higher peak (dorsi) flexion of the ankles and trunk when standing up to move body weight closer to their base-of-support and maintain postural stability ⁵⁹. Although Guarrera-Bowlby and Gentile ⁶⁰ indicate that older children utilise a similar movement pattern to adults, children demonstrate inconsistency between trials due to adjustments required to continually aid postural instabilities.

All movement patterns face enduring control challenges during childhood due to the ongoing changes in morphology requiring constant updates to internal control models ⁶⁰. Nonetheless it is accepted that the formative years is an optimal time to train skill and movement competency because the neuromuscular system is most susceptible to change and neural plasticity ⁶¹. Neural maturation provides movement possibilities, but continual practice and refinement of motor patterns cultivate form and consistency evident in adulthood ⁶⁰. Therefore it is

necessary to investigate if the criteria for foundation movement assessments are viable to screen both neurologically immature and advanced movement patterns.

Motor control is age-related but not age determined ⁶². Robertson ⁶² recognised that motor development of fundamental sports skills generally follow the same sequence between individuals, but the age at which they progress could be different. Masci et al. ⁶³ caution that it cannot be assumed that children of the same chronological age would necessarily be at the same level of developmental sequence. The authors demonstrated that skill development of the hop did not improve linearly with chronological age, suggesting that individual constraints and exposure to movement demands may impact skill levels in school children. Continual assessment is required to understand individual levels of motor development. However, literature is inconclusive in regards to whether documented movement differences at different ages are attributed to extent of physical activity participation, sedentary activity levels or exposure to unique movement challenges ²⁴.

It is unreasonable to have the same performance expectations of school children that are expected of adults. The literature and industry bodies have defined physical literacy by the ability to perform fundamental sports skills in a range of environments. Giles suggests that foundation movements are more important than sports skills for lifelong health and performance benefits, however currently there has been no rigorous research to support foundation movement's efficacy as a screening tool. Whilst research into foundation movements is apparent, focus is placed on the associated fitness related outcomes ^{64, 65}, quantifying load or muscular strength ^{65, 66}, exercise prescription for the adult population ⁶⁷, or the authors have not provided a description of movement criteria ⁶⁴.

Table 1: movement similarities between foundation movements, fundamental sports skills, sport and play skills and activities of daily living

Foundation movement	Fundamental sports skill	Sport and play skills	Activities of daily living
Squat 41, 53, 68-72	Vertical Jump Sprint, Hop Dodge, Side Gallop	Landing from a jump or height, Skipping rope games, Elastics games, Shooting a hoop, Picking up a loose ball, Athletic stance, Sprint start, Leap frog, Surfing	Sitting down/standing up, Climbing stairs/ ladders, Manual handling actions, Tie a shoe lace, Pick an object up off the floor or bottom shelf, Get in and out of bed,
Lunge 41, 73-78	Sprint run, Skip, Hop, Dodge, Kick, Static bal- ance, Catch, Side Gallop,	Cartwheels, Handstands, Hop scotch, Basketball layup, Hand- ball, Racket sports, Single leg activity, Running activities, Climbing, Agile footwork in team sports,	Climbing stairs, Walking, Running for the bus, Gardening, Kneeling, Cleaning, Standing up from the floor, Climbing a ladder
Push up 12, 13, 21, 79	Overarm throw Strike	Handstands, Shooting a hoop, Striking with a bat/club, Support body weight, Absorbing body weight when falling, Cartwheels, Wheel-barrow walks, Swimming, Rugby tackle, Wrestling	Cleaning, Operating machinery, Manoeu- ring furniture and other large objects, Using a shopping trolley, Closing doors, Driving, Mowing
Pull up 11, 14, 79, 80	Throw, Catch, Strike	Monkey bars, Swings, Spinning, Parachute games, Climbing, Striking with a bat, Swinging, Tug- of-war, Swimming, Skipping rope games, Tennis serve	Manoeuvring a chair towards a table, Walking the dog, Pulling to stand, Sweeping/cleaning, Opening doors/ draw- ers, Picking up an object or child, Occupation tasks e.g. pulling a rope, fire hose, irrigation tube
Hinge 17, 32, 47, 79	Vertical Jump, Overarm throw, Kick, Dodge	Hand stand, Forward roll, Hand- ball, Dribbling a ball, Swings,	Leaning over, Forward bending, Sitting cross legged, Sitting down, Standing up
Rotation 9, 32, 53, 79	Sprint run, Overarm throw, Kick	Rugby tackle, Cartwheel, Crawl- ing, Baseball, Gymnastics, Catching, Handball, Racket/hit- ting sports, Golf swing, Dribbling a ball, Army crawl, Monkey bars, Rowing	Reversing a car, Balance of body weight during locomotion activity, Hold an infant on the hip, Rolling, Crawling, Standing, Walking and running, Turning in place, Stretching, Reaching
Brace 79, 81	Static balance, Overarm throw, Kick, Sprint run, Dodge	Twirling, Handstands, Rugby tackle, Forward roll, Crab crawl, Swings, Absorb force when landing from a jump or height, Hula hoop, Dance, Gymnastics	Manual handling activities, Postural stabil- ity, Management and prevention of lower back pain and other injuries, Balance, Twisting

Youth Resistance training

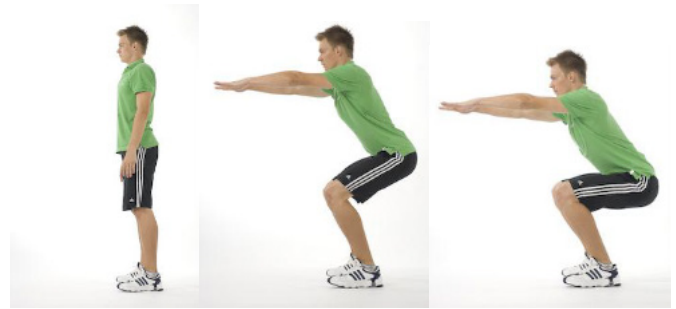
Youth resistance training benefits are well-established in research dating back to the 1950's⁸². Since then, efficacy, safety concerns, injury risk, guidelines and prescription have been heavily debated with contentious outcomes⁸³. Benefits for this population include increased strength and power, muscle development beyond levels of maturation, improved cardiovascular risk profile, enhanced motor coordination, improved body composition, injury prevention, developed bone mineral density, positive psychological influences and constructive lifestyle factors such as longevity of physical activity habits⁸³⁻⁹⁴.

The most recent youth resistance training guidelines suggest that children with adequate emotional maturity to follow instructions are capable of effective training⁶¹. The 2014 International Consensus Statement on Youth Resistance Training suggest that proper technique is prioritised as a training goal in untrained youth⁶¹. Despite chronological age, movement competency is initially developed during basic bodyweight exercises such as squatting, lunging, pressing and pulling⁶¹. Current literature outlining movement criteria for children and adolescent strength exercises is scarce. Additionally available research focuses on strength and performance outcomes of movements as opposed to control of movement. Whilst foundation movements are traditionally performed in a resistance training setting, their specific benefits and strength outcomes are not within the scope of this literature review. The following movements represent entry level criterion for the purpose of a foundation movement screen.

Squat

Significance of the squat

First appearing during the rhythmical up-and-down bouncing movement between deep squat and standing observed in infants, a deep squat is a crucial movement for infants to master on their journey to independent locomotion⁵³. Once locomotion approaches maturity at about five to seven years of age, the squat pattern is required to sit on a chair or pick up an object off the floor⁵³ (Table 1).



Movement Criteria for Success

Parallel front and back squats are highly trainable in school aged children⁶⁹. Keiner et al.⁶⁹ progressed both untrained and moderately trained soccer players between 11 and 19 years from body weight squats focussing on technique to weighted squats in a hypertrophy protocol⁶⁹. The control group who performed no specific squat training over the 8 week protocol were unable to squat past parallel due to mobility limitations whereas the strength training groups were able to perform full depth squats⁶⁹. While this study recognised movement benefits from squat training, the authors focussed on performance outcomes and were unable to explain why these improvements occurred. The squat is trained to reinforce mobility of the ankles, knees, hips and back, important for activities of daily living, sporting performance and recreational activities⁷¹. The suggested technique is as follows:

1. Start in an upright position with knees and hips at or near full extension, feet approximately shoulder width apart, or as required during specific sport and aligned in the sagittal plane^{41, 95}.
2. Heels remain in contact with the floor and knees continue to align with the toes⁹⁵⁻⁹⁷.
3. Descend until thighs are at least parallel to the ground or lower⁹⁵⁻⁹⁷.
4. Gaze remains forward or up while lordotic curve is maintained until thighs are parallel or a natural kyphotic curve may be observed during deep squats⁹⁵⁻⁹⁹.
5. Symmetrical weight distribution between legs maintains balance and posterior-lateral hip alignment to promote equal muscle strength between hips^{100, 101}.

Relationship to Fundamental Sports Skills

The squat is a movement required for most athletic pursuits, it is the main component of the athletic stance or ready position and is involved in most power movements requiring the lower extremities ⁴¹. Baker ⁶⁸ proposes that the biomechanics of a squat may transfer to the vertical jump but has not provided any evidence of this. Significant relationships have been found between squatting strength, sprint and jump performance ^{69, 70, 72}. Worldwide popularity of the squat is a reflection of its innate relationship to sports performance and activities of everyday living ⁷¹.

Characteristics required for developing the vertical jump, hop and sprint match the aforementioned biomechanics of the body weight squat (Appendix 1).

Lunge



Significance of the Lunge

Rhythmical kicking of the legs and feet performed by infants lying in supine position appear to be the earliest evidence of movements involved in the lunge (Thelen quoted in ⁵³). Common movements include (dorsi) flexion and extension of the hip, knee and ankle ^{53, 77}. Once infants approach locomotion, static and dynamic balance control is necessary for daily activities and sports performance ¹⁰². For example the forward lunge is an exaggeration of the movements involved the gait cycle ⁷⁴. The asymmetrical nature of the lunge can be physically demanding for certain populations due to unilateral weight distribution in the leading leg ¹⁰³. The lunge can be used to prevent or improve bilateral substitution

patterns as well as enhance single leg activities such as walking or climbing stairs ¹⁰³ (Table 1).

Movement Criteria for Success

The lunge assesses dynamic joint range of motion and flexibility of the lower extremity in the sagittal and frontal planes. The body weight forward lunge is considered the introductory activity to more advanced lunge variations ¹⁰³. The suggested technique is as follows:

1. Head, trunk and arms controlled by the pelvis, observed in maintenance of horizontal hip alignment when viewed from the front ^{74, 104}.
2. Maintains balance over centre of mass throughout weight transfer without support leg flexing ^{63, 74, 104}.
3. The fixed foot must maintain its position on the floor and not rotate in or out ⁷⁴.
4. Front knee in line with the small toes and over the ankle upon landing, shin remains vertical ⁷⁴.
5. A successful lunge requires a smooth transition back to the starting position ⁷⁴.

Relationship to Fundamental Sports Skills

Forward lunge assessment is used by practitioner's to observe hip, knee and ankle range of motion during weight-bearing movement in the sagittal plane ⁷⁴. The forward lunge is favoured as a practical screening tool because of its close relationship to an individual's sporting or recreational demands ⁷⁴. Cronin et al. ⁷⁵ recognise that like the lunge, most athletic activities involve unilateral propulsion. The upright, multiplanar, gravity based environment that the forward lunge assessment demands, require the same movements as some fundamental sports skills. Masci et al. ⁶³ assessed hopping development in school aged children and documented similar biomechanics to the forward lunge including hip and knee flexion of the moving leg, smooth transfer of weight and knee extension of the support leg. Additionally Gallahue and Ozmun ⁵³ indicate that the static balance, skip, kick, overarm throw, dodge, run and utilise weight transfer biomechanics learnt during a forward lunge exercise ⁷⁴ (Appendix 1).

Push (modified push up)



Significance of the Push

The push is observed as early as four months within parachute and propping reflexes where an infant attempts to brace before an apparent fall, the limbs will extend, tense and abduct⁵³. Reflexive and voluntary crawling requires significant effort towards pushing, observed around the fourth and seventh month respectively⁵³. When learning to stand, an infant pushes into a quadruple position, extends through the trunk into a deep squat in order to become erect ready for locomotion²¹. Beyond infancy the push is required during activities of daily living such as closing doors, pushing a shopping trolley, moving objects or task specific fundamental sports skills (Table 1). During injury rehabilitation the push up strengthens the serratus anterior, important for scapula control¹⁰⁵.

Movement Criteria for Success

Different loads have been quantified for push up varieties. Bent knee push-ups provide a load of approximately 49% body weight whilst regular push-ups performed on the feet can provide a load of up to 64% body weight⁶⁶. Consequently an individual's body composition will affect the amount of load they are required to push⁶⁴. Therefore the entry level movement involves a four-point push-up with knees flexed supported on the floor¹⁰⁶. The suggested technique is as follows:

1. Chest lowered until upper arms are positioned at least 90° in relation to the ground^{67, 106}.
2. Neutral spine, head in line with trunk and

vertebral column^{67, 107}.

3. No internal or external rotations of the upper extremity, i.e. shoulders remain square with no cervical rotation, flexion or extension¹⁰⁷.
4. Shoulders, spine and legs maintain a straight line^{67, 106}.
5. Hands placed directly under shoulders^{66, 67, 106}, weight even between hands with no movement towards one side¹⁰⁷.

Relationship to Fundamental Sports Skills

The human push capability involves 'strength, weight, weight distribution, push angle, floor friction and friction between the upper body and pushed object' (¹⁰⁸ p.293). The push up assesses and trains strength, weight distribution and upper body friction between the hands and the ground. One of few closed-chain upper body exercises, various forms of the push up exercise are performed during strength exercises to challenge the muscles of the torso, chest, back, arms and shoulders^{66, 67}. Push-ups are commonly used as a test of muscular endurance in outcome based assessments⁶⁶. The gleno-humeral joint is the most mobile joint in the body requiring stability and mobility throughout daily tasks, recreational and sporting activities¹⁰⁷. Therefore the dynamic and static nature of the different stages of the push up appears to be the optimal injury prevention and muscle strengthening movement required for most upper body skills¹⁰⁷. Specific fundamental sports skills that may require similar biomechanics associated with the push up include overarm throw and strike (Appendix 1)

Pull (modified pull-up)

Significance of the Pull

The pull-up reflex of the arms is assumed by infants from 3 months in an attempt to maintain upright position when tipped forwards or backwards⁵³. This action develops at about 12 months old when a toddler begins to pull themselves up to standing^{53, 109}. The pull action is seen during play when climbing, swinging or striking and as adults the pull is used during occupational and daily tasks (Table 1). The pull up

challenges spine stability important for rehabilitation and athletic performance ¹¹⁰. Spine stability relies on optimally coordinated muscle contraction around the spine providing stiffness and an ability to maintain or recover original position after being stressed during athletic requirements or daily activities ¹¹⁰. Training stability through pull exercises is crucial for injury prevention and maintaining independent living ¹¹⁰.



Movement Criteria for Success

Performance difficulties in traditional pull-ups have been reported in children. Lloyd et al. ⁶⁴ tested eleven and twelve year olds pull-up ability, 71% of children could not perform a regular pull-up which involved gripping a bar while standing and vertically lifting body weight off the ground. Pate et al. ⁶⁵ reported similar difficulties with a traditional pull-up but found that performance in a modified pull-up in a supine position with heels on the ground yielded a normal distribution. These authors have provided modifications to previously accepted exercise techniques for children which is a big achievement towards targeted exercise technique for children. The modified pull-up is the most valid and appropriate test for 9-10 year old upper body muscular strength because it is less weight and gender dependent ⁶⁵. Additionally this technique produces small compressive and shear forces on the spine due to the neutral spine angles ¹¹⁰. Therefore it may be the most appropriate pulling exercise for beginners or children who have immature spine stability ¹¹⁰. The suggested technique is as follows:

1. Upper body pulled until horizontal to the ground ¹¹⁰.
2. Rigid trunk maintained throughout ^{106, 111}.
3. Heels, hips, shoulders and head remain in the same straight line ⁶⁵.

4. Weight even between hands, no movement towards one side ¹⁰⁷.
5. Shoulders, spine and legs maintain a straight line ^{67, 106}.

Relationship to Fundamental Sports Skills

Pull exercises activate back muscles with a particular focus on muscles controlling the thoracic spine ¹¹⁰. Youth field assessments typically assess the pull up as a measure of upper body strength ⁶⁵. Fundamental sports skills requiring a back swing, wind up, pull, swing or 'give' when catching could benefit from the pull up. The pull action is most observable during a catch, overarm throw or strike (Appendix 1). Sports that rely on the pull include rowing, kayaking, water skiing, baseball, cricket, swimming, tennis and gymnastics ¹¹⁰.

Hinge



Significance of the Hinge

Ability to apply correct hip hinge mechanics during lifting, sitting down and sit-to-stand reduces end range spine flexion, a major cause of lower back pain ¹¹². Tightness through the lumbar spine, hip external rotators, internal rotators and hamstrings may cause an individual to use their waist to bend instead of their hips, evident in rounding of the thoracic and lumbar spines ¹¹³. Rounding through the spine during daily activities and athletic training will cause excessive stress on the intervertebral disks ¹¹³. Adopting the correct hip hinge technique puts the spine in neutral alignment

allowing trunk muscles to efficiently stabilise the spine ¹¹³. Hip hinge mechanics are commonly trained to strengthen the lower back, hips and hamstrings, beneficial for lower back rehabilitation and sporting pursuits such as cycling, equestrian and diving (Table 1) ¹¹⁴.

Movement Criteria for Success

The suggested technique is as follows:

1. Hinge at the hips to maintain neutral spine with natural lordotic curve of the lumbar spine ¹¹²
2. Head remains in neutral alignment ¹¹⁴.
3. Knees remain straight with no excessive bending throughout the movement, but not locked out at full extension ¹¹⁴.
4. Symmetrical weight distribution between legs to maintain balance ¹⁰⁰.
5. Scapulae retracted to maintain natural curve of upper back, a kyphotic spine curvature should be avoided. Downward motion ceases when a stretch is felt in the hamstrings ¹¹⁴.

Relationship to Fundamental Sports Skills

Correct hip hinge mechanics are important for strength exercises including the squat ¹¹³. Ability to control trunk musculature, stabilise the spine and break at the hips is crucial to injury prevention and to utilise the entire kinetic chain ¹¹⁵. Improper control will result in propulsive forces being absorbed instead of transferred through the trunk ¹¹⁵. Adequate range of motion of the lower back, hamstrings and gluteals allow proper flexion at the hips and is important for success during the kick, overarm throw and vertical jump ^{53, 116} (Table 2, Appendix 2).

Brace (prone plank)



Evolution of the Brace

Torso musculature begins to activate when the infant in a prone position arch their back and lift

their arms and legs from the ground rocking backwards and forwards ⁵³. Between two and eight months, evidence of trunk stability is seen as the infant lifts their head and chest off the ground from a prone position, perform supine-to-prone roll and sits independently ⁵³. Trunk control is increasingly developed to crawl, reach and grasp, and for locomotion ⁵³. Teenagers with faulty posture and poor postural muscle tone have been reported to have reduced trunk rotation ability ¹¹⁷. Therefore training of postural muscles through movements such as brace, push, pull and hinge may improve posture and rotation. Muscles of the trunk that are trained during the brace control the spine, pelvis and kinetic chain during most movements involved in daily and recreational activities ⁸¹ (Appendix 1).

Movement Criteria for Success

The prone plank tests ability of the individual to maintain a neutral back position ¹¹⁸. Like the push it is desirable to reduce load on a beginner's spine, muscles and joints. Therefore the entry level brace position is assumed on flexed knees and elbows. The suggested technique is as follows:

1. Trunk remains straight throughout, a straight line should be able to be drawn from the shoulders to ankles through the hips ¹¹⁸.
2. Neutral spine, head in line with trunk and vertebral column ^{67, 107}.
3. Weight remains even between both arms with no movement towards one arm ¹⁰⁷.
4. No internal or external rotations of the upper extremity, i.e. shoulders remain square with no cervical rotation, flexion or extension throughout movement ¹⁰⁷.
5. Athlete was able to hold for a proportion of recommended adult time – 30 seconds ¹¹⁹.

Relationship to Fundamental Sports Skills

The prone plank creates a basic motor pattern that results in activation of the trunk musculature ¹²⁰. Strength and conditioning practitioners place great focus on trunk stabilisation for enhanced performance, injury prevention and rehabilitation of lower back pain and injuries ⁸¹. Trunk stability

provides proximal stability for distal motion during recreation and sports pursuits and an important platform for controlled coordination ⁸¹. Once the motor pattern is ingrained, more specific exercises can be incorporated that challenge the athlete's balance, posture and trunk control specific to their athletic pursuit ¹²⁰. Control of trunk musculature plays a role the transfer of force between the upper and lower kinetic chain during an overarm throw or kick ⁸¹ (Table 2).

Rotation



Significance of the Rotation

Reflexive and voluntary rotations are observed in infants from four to five months ¹¹⁷. Neck and body righting reflexes allow an infant to move their hips and legs into alignment with their head followed by their trunk ^{53, 117}. The development of rotation and postural alignment appear successively in the sagittal, frontal and transverse planes and play a crucial role in postural tone and development ¹¹⁷. Infant rotation is observed as they roll, crawl, stand, walk and turn in place ¹¹⁷. At all life stages rotation is the foundation of various forms of locomotion, adapting the posture of the upper body, increasing the range of the upper limbs and maintaining body balance during movement ¹¹⁷. Walking is the most common locomotion required by humans and its efficiency relies heavily on adequate rotation between upper and lower limbs. Rotary movement of the pelvis causes counter movement of the opposite shoulder to keep the body in balance ¹¹⁷.

Rotation tests primarily assess the ability of the pelvis to disassociate with the upper extremities, important for momentum transfer and to avoid energy absorption at the pelvis ^{121, 122}. Activities that require adequate rotation include rolling, quadruped position, sitting, standing, walking, turning, reaching behind the body, stretching or reversing a car ¹¹⁷ (Appendix 1).

Movement Criteria for Success

Accurate assessment of spinal rotation is used for injury rehabilitation and performance-enhancement interventions and can help identify imbalances that need to be addressed clinically. Regular tracking of spinal rotation can also provide feedback on training or intervention progress ¹²³. The individual starts standing with feet shoulder width apart ¹²¹. The suggested technique is as follows:

1. Trunk remains straight throughout, no slumping or arching in back ¹²⁴.
2. Body remains vertically aligned with no sideways, hip hitching or side bending at the lumbar spine ¹²⁴.
3. Shoulders remain in a horizontal alignment ^{123, 124}.
4. Feet and knees remain facing the front during rotation, while pelvis will rotate in the opposite direction to the shoulders ¹²¹.
5. Able to rotate symmetrically at least 90 degrees, able to see anterior shoulder of the opposite side ¹²¹.

Relationship to Fundamental Sports Skills

Thoracic rotation contributes to range of motion available in the shoulders, therefore any skills requiring mobility through this joint requires adequate axial rotation ¹²⁵. Poor axial rotation is associated with reduced muscle forces around the scapular leading to injury risk and performance detriments ¹²⁵. Trunk rotation is pivotal to energy transfer between the lower extremities, pelvis and upper extremities ^{115, 121, 126}. Conversely inadequate or asymmetrical rotation through the trunk and spine can disrupt movement of energy through the kinetic link and lead to less efficient movement or

athletic performance¹²¹. The overarm throw is used during sporting pursuits and simple tasks such as throwing a scrunched up piece of paper in the bin¹²⁷. Rotating through the upper torso and pelvis is a reflection of mature skill development and provides a faster ball velocity¹¹⁶. According to Gallahue and Ozmen⁵³ rotation of the trunk and shoulders during overarm throw appear during the elementary stage of skill acquisition and refines once skill development matures. Rotation through the shoulders and trunk is key to taking advantage of the kinetic link principle during the kick¹²². More skilled kickers show better rotation between the non-kick side shoulder and the kick side hip¹²². Rotation through the trunk and shoulders is crucial to running, kicking, skipping, hopping, striking and basketball dribbling^{53, 128} (Table 2, Appendix 2).

Summary

Foundation movements proposed by Giles appear to have logic as an assessment of movement deficits and underpin movement requirements for fundamental sports skills. Current research focus on the adult population, are outcome oriented, apply to trained athletes, assess strength components or do not supply a criteria for success for a child or adolescent. Significance of each foundation movement lies in the biological beginnings of the movements developed during infancy. Postural changes throughout maturation or inadequate opportunity for refinement of foundation movements may contribute to poor fundamental sports skills observed in school children. Foundation movements could be considered both individually and as a set. The possible relationship between foundation movements and fundamental sports skills can be seen in Table 2, Appendix 2. Foundation movements have both similar and unique characteristics that work together to create human motion. Criteria for success for each movement have been adapted from the literature and focus on the entry level application for each movement pattern. Further study into foundation movements is warranted to investigate whether the criteria set out is appropriate for the school aged population.

CONCLUSION

The goal of this literature review was to provide a rationale for considering foundation movement competencies as a preliminary assessment to fundamental sports skills. A major gap in the body of literature was a physical assessment that objectively quantifies movements needed to improve fundamental sports skills. Foundation movements may be relevant to succeed in physical education and enhance the physical literacy journey. Implications of this research could inform future assessment protocols in both physical education and physical literacy globally. The foundation movement assessment appears to have a relationship to skills involved in the New South Wales physical education curriculum, 'Get skilled: Get active'. However no rigorous scientific research has been conducted to justify the relevance of foundation movements to school children. Furthermore in order to determine the significance of these movements as a movement assessment, it is necessary to investigate whether physical activity, sedentary activity, age or weight status effect foundation movement competencies.

Following this study there will be a clearer understanding of criteria to test foundation movement competencies in school children. Additionally an understanding will be reached on the impact lifestyle factors have on foundation movement performance. This study will provide baseline measurements for further study into programming for movement improvement.

It is hypothesised that better scores in foundation movements assessment will translate to greater scores in fundamental sports skills. Secondly it is thought that children who fulfil the daily requirements of physical activity will attain better scores in both foundation movement and fundamental sport skills.

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APPENDIX ONE

Mechanisms of Fundamental Sports Skills outlined in “Get Skilled: Get Active” and the associated foundation movements.

Static balance mechanics	Associated foundation movement competency
- Static balance occurs when a person’s base of support is stationary. Bearing weight on a variety of body parts requires static balance 129. - The bodies’ centre of gravity is aligned over the base of support. Strength and flexibility are necessary for controlled balance, muscle power may be necessary to regain balance and flexible joints are required to position body to maintain balance 129. - When a small external perturbation or internal unsteadiness occurs, muscles engage to resist the force of the centre of gravity moving away from the base of support. Specific muscles used to regain and maintain balance include the gastrocnemius which initiates plantar flexion to resist forward motion of the body, hamstrings and iliopsoas to maintain hip and knee stability and the thoracic erector muscles help the trunk move back into alignment. If the perturbation is larger the abdominals and quadriceps will also engage to regain control 130. - Support leg still, foot flat on the ground while non-support leg bent 10. - Trunk stable and upright, head stable, eyes focused forward 10. - No excessive arm movements 10	Several foundation movements challenge and support static balance development: <u>Lunge</u> - Maintains balance over centre of mass of support leg throughout weight transfer 63, 104. <u>Squat</u> - Promotes symmetrical weight distribution between legs to maintain balance and resist external perturbation. Trains muscles associated with balance and stimulates equal muscle strength between hips 100, 101. <u>Brace</u> - Wide base of support, arms and knees bare the weight providing additional static balance training. Trunk stability crucial to maintain balance 118. <u>Hinge</u> - Distribute weight evenly between feet to maintain static balance of the lower body while the upper body moves 100. - Educates individual to activate hamstring, erector muscles and iliopsoas 113
Sprint Run Mechanics	Associated foundation movement competencies
- Adopts maximum stride length and speed with a observable flight phase 53. - Complete extension of support leg at the hip and knee pull the leg forward and propel the body forward provided by back and hip extensors and plantar flexors 53, 131, 132. - Recovery leg hip flexors collectively drive the leg up and forward and is observed when the thigh is 90 degrees or parallel to ground 10, 53, 131. - Thoracic rotation allows arms to swing in opposition to legs. Movement initiated by the chest, shoulders and upper back which provide propulsive forces forwards and upwards to generate lift and upward momentum 53, 131, 132. - Lands on ball of the foot 10. - Head and trunk stable, eyes forward 10. - Elbow flexion provides approximate right angles to forearms 53. - Minimal rotary action of the recovery leg and foot 53. - Slight trunk flexion allows the centre of mass to be ahead of the legs aiding acceleration whilst maximal speed is characterised by a more upright upper body 131-133.	Compound exercises such as the squat, hinge and lunge develop deeper angles of joint extension in the knees and hips while load is carried in the trunk to train core stability. Push, pull and rotation aid arm drive and propulsive forces whilst the hinge promotes trunk flexion and stability which is important for all speeds and phases of running 131. <u>Squat and Hinge:</u> - Squat and hinge exercises train the back extensors to engage during running which is important for trunk support during acceleration phase 131. - Hinge exercises train correct trunk flexion and stabilisation mechanics while activating hamstrings and gluteals which are pivotal in hip extension during sprint running 132. <u>Push and Pull:</u> - Train the movement pattern of the shoulders, chest and upper back which is key to producing propulsive forces and momentum through the arms and upper body 53, 66, 67, 131. <u>Lunge:</u> - An exaggeration of the movement patterns required during the gait cycle, the lunge promotes balance throughout transition period while maintaining centre-of-mass over base-of-support 63, 74, 104. - Lunge varieties assess and train leg extension, hip and knee flexion and movement without shin of trail leg rotating in or out all important for skilled sprint running 53, 131. <u>Rotation:</u> - Arm swing and shoulder rotation act as an elastic linkage between the lower body, shoulders and arms. Running without an adequate arm swing leads to higher energy cost. Axial rotation of the thoracic spine is a major contributor to shoulder range of motion. Therefore learning proper shoulder and trunk rotation is important for arm swing and economy of movement during sprint running. 123, 134

Dodge Mechanisms

- Lateral trunk flexion allows the body weight to shift in a fluid manner in the direction of the dodge. These body positions are required to produce forces to the ground and benefit from reactive forces in the opposite direction [53](#), [133](#).
- Knee flexion and slight trunk flexion allows the body to lower during change of direction and to push off the outside foot [10](#), [53](#), [133](#).
- Rapid hip and knee extension produce powerful lateral ground reaction forces which if the trunk is stable, is effective in transmitting the propulsive force through the entire kinetic chain [133](#).
- Mature dodging skills demonstrate equal ability to dodge to the left and the right and perform change of direction in one step with the eyes focussed forwards [53](#).

Associated foundation movement competencies

Brace:

- Trunk stability has been identified as crucial for change of direction movements as it can either absorb or transmit the propulsive forces through the kinetic chain. The more conditioned the trunk musculature the better it can transmit the force [133](#). Most foundation movements challenge trunk stability. The brace statically challenges trunk alignment while the squat, lunge, hinge, rotation push and pull promote stability around the spine during dynamic movement [67](#), [84](#), [106](#), [107](#), [111](#), [112](#), [135](#).

Hinge:

- Stimulates trunk flexion from the hips which promotes trunk stability and safe lumbar spine loading while lowering the body during the dodge [113](#).

Lunge:

- Weight transfer and balance is important during the dodge and can be trained during lunge exercises which involve single leg balance during weight transfer between legs [63](#), [104](#).
- Additionally it has been recognised that unilateral loading trained during the lunge is beneficial to single leg skills such as dodging [103](#).
- Asymmetrical nature of the lunge can address imbalances between the left and right sides during the dodge.

Hop mechanisms

- Quick triple flexion-extension of the hip, knee and ankle pull foot off the ground for momentary flight. The swing leg is lifted high and held statically in front of the body [136](#).
- Non-support leg stays high without any collapse through the hips. Ankle, knee and hip remain square in alignment [53](#).
- Slight extension of the knee and ankle combined with a slight hinge of the trunk and gravity allows the body to fall forward in propulsion and triple flexion of the supporting leg helps regain balance to land [136](#).
- Observable pre take-off triple extension of the support leg begins the transition to the next legs movement with little delay between stability flexion and projectile extension [136](#).
- On landing weight is transferred to the ball of the foot before the knee and ankle extend to take-off [136](#).
- The swing leg begins forward action well before initiation of knee extension in the support leg [136](#).
- Head stable, eyes focused forward throughout the jump [10](#).
- Arms bent and swing forward as support leg pushes off [10](#).

Associated foundation movement competency

- Single leg hops place a high demand on the leg muscles to generate enough moment and power around the knee joint to facilitate take-off and absorb eccentric landing forces [137](#). Therefore lower body movements that promote power through triple flexion-extension of the hip, knee and ankle will aid this skill.

Squat:

- Train mobility through hip and ankle dorsiflexion-extension as well as stability at the knee and lumbar spine. Additionally power is generated and trained through these joints during the concentric phase of the movement [41](#), [55](#), [95](#).

Lunge:

- Adequate hip range can also be trained with lunge exercises as the student is encouraged to lunge until the shin is vertical with the foot [74](#).
- Forward and return movements trained during the lunge necessitate single leg balance throughout transition period while maintaining centre-of-mass over base-of-support. The shin, hip and knee remain aligned to return smoothly to supporting leg. The swing leg is required to step high over the height of the support knee [63](#), [74](#), [104](#).
- Like the hop, the lunge relies on unilateral propulsion, teaching the lead leg to bare the greatest amount of load and resistance [103](#).

Rotation:

- Axial rotation is necessary through thoracic spine to provide adequate range of motion in the shoulders for the arms to swing in sync with leg movements [125](#).

Vertical Jump Mechanisms

- Characterised by high force production in a short period of time, produced by lower body extensor muscles [68](#).
- Coordinated recruitment of the trunk, arms and lower limbs are required to squat down until thighs are parallel to the ground, or knees are flexed from 60 to 90 degrees. Eyes focus forwards and up [14](#), [53](#), [54](#), [138](#).
- Upon transfer into the up phase or explosive phase, forceful triple extension of the hip, knee and ankle will utilise the stretch shortening cycle. Legs straighten in the air with simultaneous coordinated upward arm lift is required to jump vertically as high as possible [14](#), [53](#), [138](#).
- The knee extensors contribute the most work towards the vertical jump followed by the hip and ankle extensors [68](#).
- Controlled landing relies on triple flexion of the hip, knee and ankle as the feet contact the ground simultaneously, about shoulder width apart, toes touching first and return to the starting position [14](#), [53](#), [138](#).
- Trunk remains stable and upright throughout [54](#).
- Controlled landing with no more than one step in any direction [10](#).

Associated foundation movement competency

Squat:

- Synchronised triple flexion of the hip, knee and ankle is essential during the crouching and landing phase of the jump and eccentric phase of the squat alike [95-97](#).
- It appears that general squat training will train the contractile capabilities of the muscles involved in the vertical jump, meaning that neuromuscular properties of muscle involvement will increase and in turn improve the vertical jump movement, specifically jump height [68](#).
- The squat trains mobility at the ankle, hip and thoracic spine along with stability at the foot, knee and lumbar spine important for shock absorption when landing [139](#).
- Triple extension of the knees, hips and ankles provide the power needed in both the squat and vertical jump to powerfully move body mass against gravity and create the concentric phase of the movement and skill [68](#).
- Proper squat mechanics teach an individual to maintain a shoulder width stance and align the knees with the toes in the sagittal plane [41](#), [55](#), [95](#).

Hinge:

- Hip flexion-extension is crucial to proper mechanics during the concentric and eccentric phases of the vertical jump [68](#). Ability to initiate this movement by engaging the psoas while hinging at the hips as opposed to the waist maintains neutral spine alignment and will decrease impact to the intervertebral disks during landing from a jump or height [113](#).

Kick mechanics

- Muscles involved in the kicking leg provide power and ball velocity, while muscles of the supporting leg are involved in stability so that the whole kinetic chain is used to rotate the body and swing the kicking leg quickly [144](#).
- Knee extensor and hip flexor muscles play a key role in kicking performance [144](#).
- The kick is initiated at the hips and movement follows a proximal to distal segmental sequence, i.e. foot trails the hip, thigh, knee and lower leg [122](#).
- Kicking foot hip extension and knee flexion perform concurrently with trunk rotation towards the non-kicking leg during wind-up [122](#).
- Powerful synchronised knee extension and ankle dorsiflexion initiate ball contact, simultaneously with hip flexion and trunk rotation towards kicking leg as well as arm flexion and adduction on the non-kicking side [122](#).
- Slight knee flexion of non-kicking foot upon ball contact [53](#).
- Trunk flexion during follow through [53](#).

Associated foundation movement competency

Squat:

- Evaggalos et al. [144](#) found that training specific movements positively changed kick biomechanics, resulted in a more explosive backward and forward swing as well as increased muscle activation during critical phases of the kick. Movements taught include knee flexion and extension and ankle dorsiflexion and plantar flexion, accomplished through squat training. These movements also feature in the lunge movement [77](#).
- Triple extension of the knees, hips and ankles provide the power needed to move body mass against gravity required during the concentric stage of the squat and swing phase of the kick [68](#).

Lunge:

- Unilateral loading of the lead leg during a forward lunge challenges both weight transfer and balance required during the kick [63](#), [75](#), [103](#), [104](#). Additionally the asymmetrical nature of the lunge can be used to train the left and right components of the kick separately [103](#).
- Support leg knee and hip extension concurrent with non-support knee and hip flexion and ankle dorsiflexion to absorb weight transfer [74](#). These biomechanics are mirrored during the kick [122](#).

Rotation:

- Separation of hip flexion from lumbar flexion allows upper body rotation and hip flexion to occur separately [121](#). This aids kicking power and energy transfer through the torso [122](#).

Side Gallop Mechanisms	Associated foundation movement competency
- The leading leg produces shock absorption and breaking force 140. - With the weight on the balls of the feet, trailing leg absorbs the impact of foot contact and generates propulsive forces 10, 140. - Characterised by a smooth rhythmical movement with both a double support phase and flight phase 10, 140. - Hips and shoulders point to the front while the head is held stable and eyes focused forward or in the direction of travel 10.	<u>Lunge:</u> - Both the skip and the lunge relies on unilateral propulsion, teaching the lead leg to bare the greatest amount of load and resistance 103. - Promotes balance throughout transition period while maintaining centre-of-mass over base-of-support 63, 74, 104. <u>Squat:</u> - Synchronised triple flexion of the hip, knee and ankle is essential during the landing phase of the side gallop to absorb the bodies load 95-97, 141. - Extension of the knees and ankles provide the powerful concentric phase of the squat and to propel the body mass off the ground during the side gallop 68, 141.
Skip Mechanisms	Associated foundation movement competency
- Skipping involves a combination of walking and running in a single stride in which the flight phase alternated with the contact phase 142. - Double support and flight phase evident 143. - To initiate propulsion, plantar flexion of the ankle precedes extension through the ankle, knee and hip joints, in that order, which allows stability and transfer of weight to non-support leg. Hip extension is gradual, maximum extension is achieved at take-off 141. - Initial foot contact is immediately followed by knee flexion and ankle dorsiflexion to absorb the bodies load 141. - Foot contact is unevenly spaced and one leg is always in front of the other suggesting a prolonged single leg weight transfer is utilised 141. - Landing leg is vertical, strikes with a highly extended hip and flexed ankle and lands in front of the centre of mass 141, 143. - The arm opposite the stepping leg pump forward and up in sync with the leg and reverses the action once the leg has made contact with the ground. Meanwhile the arm on the non-stepping leg moves backward and down in opposition to the stepping leg 141.	<u>Lunge:</u> - Both the skip and the lunge rely on unilateral propulsion, teaching the lead leg to bare the greatest amount of load and resistance 103. - Promotes balance through transition maintaining COM over base-of-support 63, 74, 104. - Lunge varieties assess and train leg extension, hip and knee flexion and movement without shin of trail leg rotating in or out all important for skilled sprint running 53, 131. - Front knee lands in line with and over the ankle upon, shin remains vertical 74. - The shin, hip and knee remain aligned to return smoothly to supporting leg. The swing leg is required to step high over the height of the support knee 63, 74, 104. <u>Squat:</u> - Assessment of bilateral flexion-extension of the ankles, knees and hips may be ideal to train movement requirements of the skip in a stable environment 103. - Like the squat, synchronised triple flexion of the hip, knee and ankle is essential during the landing phase of the skip to absorb the bodies load 95-97, 141. - Extension of the knees and ankles provide the powerful concentric phase of the squat and to propel the body mass off the ground during the skip 68, 141. <u>Brace and rotation:</u> - Well-conditioned trunk musculature practiced during the brace provides better ability to transmit propulsive forces through the kinetic chain required for moving the body mass against gravity 133. - Axial rotation is necessary through thoracic spine to provide adequate range of motion in the shoulders for the arms to swing in sync with leg movements 125. - Trunk musculature and axial rotation work together to provide range of motion and adequate propulsive forces to pump the arms forward and up, and back and down 135. <u>Push and Pull:</u> - Train the movement pattern of the shoulders, chest and upper back which is key to producing propulsive forces and momentum through the arms and upper body 53, 66, 67, 131.

Over arm throw mechanics	Associated foundation movement competency
- Greater stride length, faster rotation of the torso and pelvis and greater trunk tilt forward are associated with advanced skill development and faster throwing velocity during overarm throw 116. - Transfer of weight to the front foot is initiated by body weight being shifted forward by hip and knee flexion on non-support side and knee and hip extension on support side 115. - To take advantage of the kinetic link from the legs through to the hand, rotation through thoracic spine and trunk is initiated at the same time as foot contact 115. - Transfer of energy from the trunk to arm comes from forward linear motion initiated by hip flexion and rotational movement between the pelvis and upper torso 115, 121. Trunk rotation in the transverse plane and extension/flexion in the sagittal plane produces the energy transfer from the legs to the arms via the pelvis and torso 121, 126. - The front leg extends to allow a stable base for the trunk to complete rotation (Fleisig et al. quoted in 115). - Simultaneous to trunk rotation, after ball release the shoulder and elbow extend as the arm follows through across the body and aids in decelerating the arm. - The thrower returns to a balanced position and the movement is completed 53.	<u>Push:</u> - Used to train activation of anterior shoulder musculature (pectoralis major, anterior deltoid, subscapularis) which works to facilitate extension of the arm during overarm throw 115. <u>Lunge:</u> - Requires unilateral loading of the front foot and balanced weight transfer from the support leg to the non-support leg 63, 75, 104. - As the support leg knee and hip remains extended, the non-support leg absorbs weight transfer through knee and hip flexion and ankle dorsiflexion 74. - Cronin et al. 75 maintain that the front foot in a forward lunge should be placed in front of the body 1.5 times the individuals leg length, whilst Stodden et al. 116 promote longer stride lengths for increased ball velocity in the overarm throw. <u>Rotation:</u> - Trunk rotation and mobility requires disassociation between the pelvis and the upper extremity which is central to taking advantage of kinetic transfer between the lower and upper extremities. <u>Hinge:</u> - Correct trunk tilt can be practiced during the hinge movement. Additionally mature hinge mechanics will ensure trunk tilt is initiated at the hips, not the waist which is important for a faster throwing velocity and injury prevention. Hinge exercises ensure tightness through the lumbar spine, hip external rotators and hamstrings is avoided and athletic performance is enhanced 112, 113.

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