2018

The General Motor Ability Hypothesis: An old idea revisited

Beth Hands

The University of Notre Dame Australia, beth.hands@nd.edu.au

Fleur McIntyre

The University of Notre Dame Australia, fleur.mcintyre@nd.edu.au

Helen Parker

The University of Notre Dame Australia, helen.parker@nd.edu.au

This article was originally published as:

Hands, B., McIntyre, F., & Parker, H. (2018). The General Motor Ability Hypothesis: An old idea revisited. *Perceptual and Motor Skills*,.

Original article available here:

http://dx.doi.org/10.1177/0031512517751750

This is the author’s version of an article published in *Perceptual and Motor Skills* available online at http://dx.doi.org/10.1177/0031512517751750

Hands, B., McIntyre, F., and Parker, H. (2018) The General Motor Ability Hypothesis: An old idea revisited. *Perceptual and Motor Skills*, doi: 10.1177/0031512517751750

The General Motor Ability Hypothesis: An Old Idea Revisited

Abstract

While specific motor abilities have become a popular explanation for motor performance, the older, alternate notion of a general motor ability (GMA) should be revisited. Current theories lack consensus, and most motor assessment tools continue to derive a single composite score to represent motor capacity. Additionally, results from elegant statistical procedures such as higher order factor analyses, cluster analyses and Item Response Theory support a more global motor ability. We propose a contemporary model of GMA as a unidimensional construct that is emergent and fluid over an individual's lifespan, influenced by both biological and environmental factors. In this paper, we address the implications of this model for theory, practice, assessment and research. Based on our hypothesis and Item Response Theory, our Lifespan Motor Ability Scale can identify motor assessment tasks that are relevant and important across varied phases of lifespan development.

Key words

Motor assessment, motor ability, motor development

Introduction

Motor ability is generally understood to be expressed in skilled, general body coordination through an ability to organise the body to produce smooth, well-timed movement in response to (or emerging from) interactions with practice conditions, task requirements and organismic constraints (Fleishman, 1964; Gubbay, 1975; Newell, 1986; Sugden & Keogh, 1990; Sveistrup, Burtner,& Woollacott, 1992). Schmidt (1991, p.129) defined this ability as “an inherited, relatively enduring, stable trait of an individual that underlies or supports various kinds of motor and cognitive activities, or skill”. Terms such as athletic talent or natural athleticism commonly embody this concept.

While this notion of a general motor or athletic ability has been popular since early last century, scientific evidence for it has proved both elusive and controversial. In early empirical psychomotor investigations, researchers like Brace (1930) and McCloy (1934) sought to discover the meaning of a singular motor ability that might underlie motor tests capable of predicting both general athletic achievement and the ease of learning new motor skills. Then, with the advent of factor analysis (Spearman & Jones, 1950; Thurstone & Thurstone, 1941) capable of identifying multiple motor skill factors from any bank of related test items, researchers became more interested in trying to identify and determine how many different specific motor abilities contributed to motor performance (Cumbee, 1954; Fleishman, 1964; Guilford, 1958; Larson, 1941; Rarick, Dobbins, & Broadhead, 1976). For example, Fleishman (1964, 1972), whose pioneering work extended from the 1950’s to the 1980’s, identified 11 psychomotor abilities (for example, multi-limb coordination, control precision, response orientation) and nine physical proficiency abilities (for example, static strength, dynamic strength, dynamic flexibility).

The low correlation values between these diverse motor abilities led motor behavior theorists to conclude that motor performance was based in task specificity (Henry, 1961, 1968; Seashore, 1930) with successful performance reliant on a discrete cluster of abilities specific to particular motor tasks. Thus, global ability theory began to be replaced by reductionism, and numerous studies supported the newer perspective. Seashore (1930), for example, tested 50 adults on eight fine motor skills and found only weak correlation values (averaging 0.25) between them. Henry (1961) compared two hypothesised specific motor abilities, ‘reaction time’ and ‘speed of movement’ and found almost zero correlation between them. Other studies comparing tasks of balance (Bachman, 1961; Drowatzky & Zuccato, 1967) and strength (Berger, 1962) found similarly low correlations. Henry (1968) concluded that even abilities like coordination and agility, considered by some as 'generic' in successful athletic performance, were specific to particular motor tasks. Thus, a newer view prevailed that individuals proficient in performing a wide range of movement skills possessed many different, specific abilities, and that patterns of specific abilities involved in successful motor performances differed among different individuals.

Efforts to clarify motor ability in terms of its heritability, responsiveness to experience and learning, and its individualized assessment have been restricted by these varying theoretical perspectives, problems with measurement methodology and by insufficient statistical procedures for identifying any single latent or underlying trait. The notion of a general motor ability (GMA) has not been supported in modern research. In this context, this paper revisits the debate surrounding the existence of a GMA and applies statistical procedures such as higher order factor analyses, cluster analyses and Item Response Theory to restore cohesion between theory and practice in motor skill assessment and the application of test results to intervention design and training principles.

Several advantages derive from accepting the notion of a GMA. First, current theoretical explanations for motor performance are fragmented, with no one theory able to account for all motor performance. A general ability notion would provide better theoretical and empirical support for tests of motor ability as 'tests of motor intelligence' similar to the concept of general intelligence (Spearman, 1904) or bodily-kinaesthetic intelligence (Gardner, 1999). Secondly, valid assessment of motor ability would assist prediction or classification of athletic achievement and the capacity, or ease of, learning new motor skills. Such assessment would provide a measure of 'good-coordination' and allow the identification of motor competence across a spectrum of motor skills, from superior to low ability, such as Developmental Coordination Disorder (American Psychological Association, 2013). Thirdly, a general ability notion would better inform and predict motor training interventions by rehabilitation therapists or physical educators since interventions designed around an individual's known capacity for learning or relearning motor skills should reduce learner frustration and injury, improve motivation, and foster skill improvement. For the purposes of this paper, we have adopted a definition of GMA, similar to Schmidt and Lee (1999), as a single trait underlying the performance of all movement skills.

Statistical Evidence for a GMA

To date, first order factor analyses of motor performance data derived from multiple tasks have seemed to provide the principal support for the existence of multiple motor abilities, distinct from a global motor ability, since, as noted above, only weak correlations between separate motor skills have been found. Further, separately identified abilities have appeared to have little in common (though the reasons provided for these distinctions may be unrelated to whether a GMA exists). However, test item selection in these assessment instruments has been determined arbitrarily and neither rooted in historical testing protocols nor framed around any theoretical model of motor ability. Additionally, within these tools, measurement and analysis methods may vary, including, for example, the use of exploratory versus confirmatory factor analytic procedures (Fields, 2013). Further, differing ages and sex of participants in psychometric investigations of these tools have precluded valid comparisons of factor analytic results between studies. Finally, Whitely (1983) reminded us that the low correlation values between tasks may reflect many influences or be related to error variance. When the same data are analysed using different techniques, the resultant factors may vary; and identifying and naming specific abilities associated with test item clusters is highly dependent on the content of arbitrarily chosen test items (Carroll, 1993). Thus, researchers have given different labels to what appear to be similar factors; and, across separate studies, the same task may even be linked with different attributes. For example, Cozens (1929) classified the vertical jump as a measure of leg strength whereas Larson (1941) labelled it as a measure of motor explosiveness. Similarly, Cozens proposed that the bar snap was a measure of body coordination, agility and control, while Larson described it as a measure of dynamic strength. The use of different labels attached to presumed underlying motor abilities persists today in commonly used motor assessments. For example, the MAND (McCarron, 1997) associates standing jump with explosive power whereas the MABC (Henderson, Sugden & Barnett, 2007) uses jumping in squares for dynamic balance. Similarly, the jump and clap task is considered to measure dynamic balance (Henderson & Sugden, 1992) or bilateral coordination (Bruininks, 1978)

Regarding low inter-correlations between specific tasks, other factors concerned with constraints from task demands, person or environment characteristics, may decrease apparent associations (Newell, 1986). For instance, the interacting factors that may reduce these correlations include differing levels of skills development or prior experience with tasks at hand (task learning); different motor demands in a given task performance such as dexterity versus strength (task characteristics); different motoric demands from the dynamic challenges of a given performance environment (open or closed tasks); or different mobility task demands (stability versus in motion); biological development and task difficulty; the physiological status of the individual (physically fit or sedentary); and skill measures with a limited score range. Without fully accounting for the effect of such extraneous factors in patterns of inter-correlation between skills, their true associations with one another may be misrepresented.

Factor Analysis

Factor analysis seeks to identify a smaller number of underlying variables or factors from large data sets by examining the inter-correlations. While the patterns of inter-correlations between specific different motor skills may be weak, this alone does not dismiss a strong underlying association between specific motor skills and the existence of a single general or global motor ability. Even though most factor analyses of motor skill test batteries have been applied in order to identify specific motor skills that accounted for a performance, several researchers have identified a general coordination factor in their first order analyses. Wendler (1938), Larson (1941), Cureton (1947), Cumbee (1954), Hempel and Fleishman (1955), and Rarick and Dobbins (1975) all identified a general factor they named Gross Body Coordination that emphasised movement of the whole body and often included the concept of agility. Later, Fleishman (1964, p. 35) explained that Gross Body Coordination involved central nervous system activity and was "the ability to integrate the separate abilities in a complex task". Previously, McCloy (1940, p.46) coined the term 'motor educability' measured within his neuromotor test of "general innate motor capacity" (p.46), arguing that this score represented the capacity to learn new motor skills. Bruininks (1978) found more than half of the test items in the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) loaded 0.3 or more on one general factor which accounted for approximately 70% of the total common factor item variance. He interpreted it as 'general motor development'. Similarly, the factor analysis of the BOTMP scores from children aged 4.5 - 5.5 years by Tabatabainia, Ziviani and Maas (1995) revealed one factor, labelled 'general motor proficiency' that accounted for 48.3% of the common variance. In the revised BOT-2, inter-correlation coefficients ranged between 0.54 and 0.80 between the Total Motor Composite and Subtest Scale Scores (Bruininks & Bruininks, 2005). A factor analysis of skills in the Test of Gross Motor Development (TGMD; Ulrich, 1985, 2000) identified one factor on which all skills loaded with an eigenvalue of 3.80. The authors assumed the skills measured a single construct known as gross motor ability.

More recently, Larkin et al. (2007) undertook a second order factor analysis of McCarron Assessment of Neuromuscular Development data (MAND, McCarron, 1997) gathered from a sample of 1,619 10-year-olds. The MAND involves 10 tasks requiring complex and varied motor skills. The second order analysis identified one single factor explaining 45% of the variance, consistent with a common, underlying construct of a general motor ability. Lämmle, Tittlbach, Oberger, Worth and Bös (2010) used confirmatory factor analysis to empirically test a two-level model of motor performance ability (MPA) using physical fitness performance data for eight tasks from 2,840 children and adolescents aged 6 - 17 years. The results provide a parallel understanding for motor ability. Their analysis confirmed a second order factor, MPA for children and adolescents, although the authors argued that it was not possible to use an overall summary score to represent MPA due to the differing dimensions of fitness ability. Lastly, Ibrahim, Heard and Blanksby (2011) assessed 330 adolescents (165 males) on 13 motor tasks. Sex-specific, second order factor analyses extracted one factor that accounted for 45.5% and 59.5% of the variance for the boys and girls, respectively. The researchers interpreted these results as evidence of a GMA or "g"factor.

Cluster Analysis

Cluster analysis involves grouping participants together, based on characteristic profiles of their scores on a set of measurements. Researchers have used cluster analysis techniques to identify subtypes of motor performance. Of note, several researchers have contrasted their identified subtypes with one that has no motor deficits with a generalised impairment across all skill areas (Dewey & Kaplan, 1994; Hoare, 1994). The subtype or participant group with no motor deficits across all test items would achieve a high score on a scale of GMA, whereas those with poor scores in some specific areas would likely have both a lower GMA and show deficits in specific motor abilities.

Item Response Theory Analysis

Item Response Theory (IRT) analyses test the fit of a given data set to an a priori expectation model and then position both test items and individual persons on a common unidimensional and additive scale. When the data fit the model, items are located along the measurement continuum according to the difficulty they present to the person, and persons are positioned according to the ability demonstrated with regard to those test items (Wright & Masters, 1982). With IRT, evidence of a GMA would be demonstrated if various items representing a range of different motor skills fit a unidimensional model. Bruininks (1978) first used IRT to equate items across different samples to validate the conversion of raw scores to standard scores and estimate total subset scores based on performance on a few BOTMP items. When the BOT-2 (Bruininks & Bruininks, 2005) was developed, item fit involving all candidate items was examined using IRT (specifically Rasch analysis). Only those items that fit the model, that is, measured a single dimension were retained in the final version. Hands and Larkin (2001) used the Extended Logistic Model of Rasch to analyze data for 24 motor skills performed by 332 five and six year old children. Given significant gender differences in motor performance, gender-separate analyses were conducted and revealed two different, unidimensional, scales of motor ability for boys and girls. Just as Thurstone (1946, p. 110) acknowledged that a second order general intelligence capacity - the "central energizing factor which promotes the activity of all these special abilities" - could exist, the same can be said for a general motor ability capacity, based on positive raw correlation coefficients, and analyses of data derived from a range of motor skills using more sophisticated procedures.

Models of a GMA

Some theorists describe motor ability as a hierarchical or a multi-tiered construct (Cratty 1966; Schmidt, 1991). Cratty (1966) envisaged a three-tiered framework of factors contributing to perceptual-motor behaviour. General cognitive dispositions such as aspiration level, arousal, ability to analyse a task, and task persistence were seen as relatively stable qualities at the highest tier, all of which might be influenced by the person's experience. At the second tier were perceptual-motor ability traits that have often been identified in factorial studies, such as static strength and extent flexibility. At the base of these three tiers was a GMA. Later, Schmidt (1991) proposed a similar three-tiered framework, presented as an inverse of Cratty's model, in which he used the term 'super-ability' to describe the overriding, global structure of motor behaviour. The second tier involved specific motor abilities (such as reaction time, finger dexterity) which made up different, but possibly overlapping, subsets of abilities contributing to the varied motor tasks placed at the base layer.

In 2001, Burton and Rodgerson proposed a four-level taxonomy of the motor domain with GMA at its base. At the top level were ‘movement skills’ (for example, striking, throwing, jumping); at the second level were ‘movement skill sets’ (skill sets, such as for jumping comprised of different forms - vertical, long, jumping jack); at the third level were ‘movement skill foundations’ (the modifiable constraints/enablers of performance, such as balance, strength, flexibility); and, at the base, was GMA. This taxonomy highlights that there are distinct genre or classes of motor functions classified at each category level and that there is no validity in deriving a summary score representing the whole cluster of individual tasks in a motor test that is drawn from the different taxonomic levels with different functional characteristics. Burton and Rodgerson argue that the assessment of surface ‘motor skills’ should be in real world, meaningful, and functional contexts in contrast to ‘movement skill foundations’ which affect current motor performance but are abilities that are modifiable with training. If one is not cognisant of the differing characteristics of task types and their differing contribution to motor ability then confusion about the notion of GMA is perpetuated.

GMA: A Unidimensional Construct

With this research backdrop, we present a contemporary model of GMA, based on Newell’s Theory of Constraints (1986), that is hypothesised as a fluid, emergent capacity to learn, control and perform motor skills across the lifespan (Figure 1). We conceive it as a unidimensional, rather than multi-layered, construct that emerges from the interacting influences of both biological and environmental factors with task demands. GMA is not directly measurable, but must be inferred from the performance of movements skills or tasks (locomotor, object control, body management skills), and strengthened by movement skill foundations (such as, flexibility, balance, reaction time, strength, muscle power etc.).

[Insert Figure 1 and Figure 2 here]

Figure 2 illustrates the key principles affecting GMA across the lifespan. Postnatally, GMA changes and adapts in response to the interaction of personal, developmental and environmental influences. It, therefore, is not a fixed, inherited capacity, but a capability that both increases and then declines across time. The initial level of motor ability in infancy and early childhood arises from the primary influence of genetics – integrity of the neurobiological system foundations, and gender of the individual. As the child develops, there is increasing influence from environmental facilitators (such as opportunity, practice, socio-cultural norms) and organismic/personal factors (such as age, motivation, resilience, physical fitness, previous learning). Optimally, GMA increases throughout adolescence, peaks in adulthood and then declines as one ages beyond mid-adulthood, again as a function of personal, biological and environmental (illness, disease, etc) factors. We elaborate on these factors below.

Biological Foundation

Integrity of biological foundations. Neurobiology is certainly implicated in motor ability. According to Fleishman (1964), the notion of a general ability to coordinate movement implies central nervous system involvement that is independent of particular body parts or muscle groups. Biological underpinnings of motor ability, therefore, likely relate to the integrity of integrated motor, vestibular, kinaesthetic and somatic systems (Gubbay, 1975; Sveistrup, Burtner, & Woollacott, 1992), and such heritable morphological characteristics as body type (Parizkova, 1996). Evidence of relative timing among groups of cortical neurons during movement tasks suggests that temporal stability or rhythmicity may be a key component of skilled motor performance (Kelso, 1997) and the ability to move quickly in response to differing situations may contribute to, or reflect, a person's overall GMA. Should any neurological subsystem for movement control be slightly impaired or undeveloped, motor performance would be compromised. Gubbay (1975, p. 3) noted "the smooth functioning of the motor system not only depends upon its anatomical intactness, but also upon the integrity of all other central structures which act upon or influence motor function." When children with Developmental Coordination Disorder (DCD) were compared to their same-age peers, they were found to have more variable muscle sequencing and timing (Geuze & Kalverboer, 1987;1994; Williams, Woollacott, & Ivry, 1992), poor precision of muscle activity (Parker, Larkin, & Wade, 1997), or poor force control (Keele, Ivry, & Pokorny, 1987), and they were slower to respond in a series of single and repetitive tasks (Schellekens, Scholten, & Krboer, 1983). Any disturbance of these integrated systems, such as a premature birth or post-natal steroid exposure (Zwicker et al., 2013), no matter how minor, may result in a reduced ability to perform skilful movement and may be described as motor impairment or a lower motor ability.

Sex. The differential effect of sex on motor performance is often ignored in motor skills research. Yet, repeated studies have identified different biological structures between males and females in motor skill assessments. Rarick and Dobbins (1975) extracted differing factor structures and motor performance typologies for 6- 9-year-old boys and girls from among 47 motor skill and physical growth measures. While they identified many similarities in factor structures between sexes, 11 sex-related typologies emerged with five person-clusters accounting for the majority of girls' motor performances and six different person-clusters accounting for the majority of boys' motor skills. Interestingly, one cluster with high mean values of strength, power and gross body coordination was represented only by boys. Similarly, a comprehensive, longitudinal study of children in New Zealand found that sex strongly contributed to gross and fine motor performance differences (Silva, Birkbeck, Russell, & Wilson, 1984), as boys performed better than girls on gross motor measures with the reverse true for fine motor measures. Silva and colleagues (1984) noted that skill differences between sexes became more pronounced in 7 year old than younger, 3 to 4 year old children. Hands and Larkin (2001) identified a gender specific general motor ability among 5 - 6 year old children, based on performance outcomes from 24 different motor skills; and they found that skill performances differed for boys and girls of similar motor ability levels. For example, skipping was more difficult for a boy, whereas kicking a large ball was more difficult for a girl. Finally, factor analyses of MAND data for a large sample of 10, 14 and 17 year-old adolescents revealed different factor structures for males and females at each age (Hands, Larkin, & Rose, 2013).

Age. Motor ability, should not be construed as static, but may be developed differentially and changed through practice and experience (that is, exposure to environmental influences). We depict this in Figure 2. One starts with a basic motor ability level driven primarily by the integrity of the biological foundations and influenced by genetics, and environmental factors then exert increasing influence with maturation. Thus, an underlying GMA may become less distinct while skill specificity in task performance seems clearer with increasing age. This implies that fewer motor test items could be used to describe younger children's motor learning capability compared to older children. Within motor test development, a wide age span among participants may have contributed to an apparent de-emphasis on the underlying GMA. Additionally, test developers have necessarily relied upon simple tasks to characterize skills of young children, meaning that test scores quickly reach a ceiling, limiting the capacity to measure small performance differences among adolescents and adults. Limited factor analytic studies of very young children suggest a strong whole body or gross psychomotor factor at that stage of development which becomes less distinct with age (for example, Meyers & Dingman, 1960). Broadhead, Maruyama and Bruininks

(1985) used exploratory factor analyses to demonstrate an increasing differentiation of motor proficiency with age; and they found that one factor accounted for 40% of the variance in 3.5 to 6.5-year-olds but accounted for only 20% of the variance in older children. Environmental influences may help account for the identification of the more specific abilities identified in older children and adults (Fleishman, 1964, 1972), but differentiated capabilities are also a function of brain development. Burton and Rodgerson (2001) reviewed a number of developmental studies that collectively indicated greater differentiation, or specificity, in motor abilities from childhood to adulthood.

Environmental Influences

Environmentally related variations in activities and skill building opportunities clearly contribute to a differential fine tuning of the relevant neuromotor subsystems and motor expressions children display (Sporns & Edelman, 1993). These differences have often been observed and reported between individuals and between boys and girls. Benenson, Liroff, Pascal, and Cioppa (1997) found evidence of a strong link between boys' masculinity (measured, for example, through toy preference, play activities and social interactions) and their propulsion ability, defined as forceful, projection action. While these researchers concluded that propulsion may be a behavioral expression of masculinity, as compared to femininity, the origins of this presumed masculinity involves differential environmental influences experienced by boys and girls that in turn facilitate aligned motor capacities.

Socio-cultural influences in play opportunities and types of games and sports valued by a culture have been well researched (Coakley & Pike, 2014). Although sport is now more global in its reach, there remain common examples of different dominant sports during development across cultures. For example, British versus American cultural influence can be seen through cricket versus baseball, netball versus basketball, and soccer versus gridiron football. Societies that differentially value physical activity involvement in childhood team sports participation may affect motor skill development. In societies where athletic talent is identified very early for elite training are apt to lead to different childhood motor outcomes than those in which there is a 'sport for all' philosophy. Often, societal wealth is reflected in part by community support of physical education and sports in school curricula. Intimately linked with societal factors is the social support given by parents, teachers (school physical education), coaches and peers for physical activity opportunities.

Optimal practice afforded by specialized coaching, modern methods of physical training, such as employing weight training, overload and recovery principles, training cycles in off and on-season scheduling, and enhanced nutrition strengthens individual motor ability within a particular domain. However, whether so narrow a focus on a single sporting pursuit facilitates or hinders optimal development of a GMA across the lifespan is unknown (Baker, 2003; Baker, Cobley, & Fraser - Thomas, 2009; Wiersma, 2000). One might surmise that developing exceptional individual talent in a particular physical endeavour does not necessarily enhance general motor capability. Indeed, Wiersma (2000) suggested that performing a limited range of skills during early sport specialization has the potential to limit overall motor skill development. Anecdotally, elite junior swimmers are often ill-adapted to play ball-sports later on with underdeveloped tracking/intercepting abilities with racquet or foot. Whilst our understanding of the mechanisms of how sport and skill specialization influences development and GMA is limited, researchers have proposed that diversification is important for our overall capacity to learn, transfer and transfer skill learnings (Baker, 2003; Baker, Cobley & Thomas, 2009).

Implications of a GMA Theory

If individual variance in motor competence is best explained by a GMA, it will be important to continue to try to understand the degree to which generic ability may be genetic, developed and changed through environmental influences (Wulf & Lewthwaite, 2009) or epigenetic in a combination of both (Holliday, 2006). Current views of the basis of motor ability favor neither exclusive hereditary (innate) nor environmental factors. Thelen's (1995) neonate and infant stepping studies demonstrated that growth (fat deposition on limbs) and the associated biomechanical constraints in air or water environments was a primary constraint on stepping behaviors. Her findings opposed the primacy of innate neural maturation as the sole explanation for the disappearance of this reflexive behaviour by around six weeks of age, and supported omnipresent environmental influences. The closely intertwined nature of biological and environmental influences is illustrated by ways in which environmental opportunities to fine tune the system through practice and experience stimulate both biological growth and the development of neural pathways thereby further enhancing motor performance and ongoing engagement with the environment. Our proposed model of GMA across the lifespan (see Figure 2) addresses the changing predominance of interactions between hereditary and environmental influences that typically occur at different points of the lifespan. Interestingly, even beliefs about motor ability play a role in motor learning capability. Wulf and Lewthwaite (2009) showed that, for young adults, learning a motor skill was enhanced by reinforcing beliefs that a person's motor ability was 'learnable' and not a fixed, inherent capacity. Accordingly, the key tenets of our GMA model are that GMA is:

- an underlying unidimensional construct representing the capacity to learn and perform motor skills;
- a level of motor learning demonstrated by performance outcomes across a variety of motor skills. It is not captured by a reductionist approach that identifies only specific motor abilities from specific task measurements;
- an emergent and fluid construct that evolves over the lifespan, tempered by both environmental influencers and person/biological factors; and
- predominantly influenced by biological foundations in infancy, increasingly influenced by environmental factors with age reverses with the biological decline associated with old age.

Implications for practice or motor interventions

If we accept the notion of an underlying, modifiable GMA, then an increasing importance must be attributed to environmental influences over the period of a person's development. However, primary methods of intervention might shift toward enhancement of GMA, rather than a focus on specific motor skills. Thus, a coach or exercise scientist might move from breaking down skills into component parts through specific task analysis and focus, instead, on developing an individual's overall motor capacity – a top down approach. The search to identify, name and train specific abilities thought to underpin a given task (the bottom up approach), risks missing the mark, given the proliferation of ways to break a task down. This does not mean there are development phases where a focus on specialised skill development is not necessary. For some populations, such as those with special needs, task analysis may be an essential form of intervention.

Since GMA is particularly amenable to opportunities to practice as an individual matures, there is considerable value in attending to whether the environmental context is or is not stimulating for physical activity and motor competence. Thus, there should be a focus on providing an environment that motivates, stimulates and challenges through a range of activities. Socio-cultural factors may act as either constraints or enablers. Recent research identifies parental physical activity, community facilities, socio-economic levels, parental employment affect males and female differently. Cross national and cross ethnic studies report effects across a wide range of ages from preschool children to adults, for example Canada (Ramos Salas, Raine, Vallianatos & Spence, 2016), Switzerland (Bürgi, Meyer, Niederer, Ebenegger, Marques-Vidal, et al., 2010), France (Deflandre, Lorant, Gavarry, & Falgairette, 2001), Australia (Caperchione, Kolt, Tennent & Mummery, 2011), South America (Goncalves, Hallal, Amorim, Araujo & Menezes, 2007) and Oceania (Mavoa & McCabe, 2008). Collectively, the studies show economic factors (parental unemployment, lower incomes), cultural values, and gender-roles adversely affect physical activity, particularly in females (Goncalves et al., 2007). Abbasi's (2014) review revealed significant barriers for females' physical activity were the lack of social support; traditional roles of childcare, household work, cultural beliefs; social isolation, unsafe neighborhood environments, rural living areas; and the absence of culturally appropriate facilities. Positive factors for physical activity included the ability for males and females to meet with friends outside school (Goncalves et al., 2007) and, for females, family or community role models (Abbasi, 2014). Of interest, 14 year old Brazilian males had greater social and family support to engage in physical activity than their female peers but, in an apparent clash with family values, many parents associated the physical activity time out of home with poor academic performance (Goncalves et al., 2007). Given socio-cultural factors are complex, and are related to sex and developmental stage these should be considered when designing and delivering interventions and training programs, including positive social support by teachers, parents, peers, and coaches.

Implications for motor assessment

There is no generally accepted, unifying theoretical framework (or taxonomy) of the motor skill domain. Terminology and labels for abilities vary and are not interchangeable between researchers and practitioners. Models of motor abilities often identify hierarchical relationships between the underpinning foundation abilities and the overarching motor ability construct, meaning that the motor ability construct still relies on multidimensional test batteries with a variety of measurement tasks that have often been arbitrarily chosen or based on historical precedence (Burton & Rogerson, 2001). Contemporary neuromotor tests, such as the Bruininks Oseretsky Test, 2nd edition (Bruininks & Bruininks, 2005), the Movement Assessment Battery for Children, 2nd edition (Henderson, Sugden et al., 2007), and the McCarron Assessment of Neuromuscular Development (McCarron, 1997) all include batteries of tasks sub-grouped into several skill domains or skill clusters, such as balance, dexterity, ball skills, or strength. Commonly, these skill ‘domains’ are justified as the underlying abilities of motor performance even though a standardized, single, summary motor score is derived from the separate item scores. In deriving this summary score, contemporary tests implicitly subscribe to the notion of a common motor factor, or general motor ability, even while they emphasize subskills. Many of these motor tests have been criticised for lacking theoretical support (Salvia & Ysseldyke, 1988) or for extrapolating dimensions of motor ability in adult samples to children or vice versa, both without empirical validation (Hands, Licari, & Piek, 2015; Lämmle, Tittlbach, Oberger, Worth, & Bös, 2010).

Re-conceptualizing motor assessment through a GMA theory re-emphasizes the importance of an underlying GMA and leads to valid, reliable motor testing that is grounded in theory, developmentally appropriate, and gender specific. If motor ability is primarily unidimensional, test items should be selected differentially in accordance with those that are suited to the age and sex of the person tested, and the overall summary score should have particular meaning. Any profile of specific abilities should be seen as secondary to a GMA, and subskills would likely be most relevant for older, rather than younger, persons. The meaning of a given test item or understanding of what it is measuring should be theoretically as well as empirically derived. There should be clarity to what a summary or composite score actually represents, as a "level of motor development" (Ulrich, 2000), motor learning capability or global motor ability. Attention should also be paid to what motor test items have the most relevance and importance for each phase of the lifespan. For example, limb coordination may matter most in infancy, while the mastery of locomotor, body management, and object control tasks matter more in childhood, power and speed become important in adolescence whereas balance and flexibility could be most important in older adults. Accordingly, we propose the development of a Lifespan Motor Ability Scale based on Item Response Theory, as presented in Figure 3. This statistical model, depicts how task difficulty would change for any one skill with each developmental phase. The example demonstrates how such task variations, in this case catching, are not merely lock-stepped with increasing age. Motor testing should select task variations according to difficulty level as established by IRT approaches.

[Insert Figure 3 here]

Implications for research

The GMA theory raises many questions and should stimulate further research. To date, the definition of motor ability and/or specific motor abilities has been driven by the broad range of test items included in various factor analyses. New statistical methodologies, such as, IRT, or Structural Equation Modelling might better explicate a GMA motor ability construct, as a number of new research questions are raised. For example, what core elements might there be to embody a general motor ability and what type of empirical research might clarify abilities in this general motor domain? We suspect that a multidimensional framework, based on an ability profile or spectrum, might better capture the fundamental nature of motor ability than one that emphasizes many specific skills. Burton and Rodgerson's (2001) taxonomy classifies movement skill foundations, motor skills, and skill sets, and this taxonomy merits empirical validation to determine whether these categories are robust in test construction. There has been a limited application of IRT methodologies to test for a unidimensional scale of motor tasks in a "goodness of fit" approach through which GMA may be inferred and examined. IRT might be applied to identify developmentally appropriate motor tasks that have relevance and importance for each phase of the lifespan (see Figure 3). It has also been rare for task analysis to be used to label specific motor abilities for a particular skill; yet this approach might facilitate consensus among researchers as to how to properly label specific important abilities. For example, is muscle power or strength and coordination most critical to the standing broad jump?

While much research revealing motor ability factor structures has neglected developmental and gender differences in motor performance, the different role that environmental experiences play in developing neuromotor systems at different ages and for males and females, respectively, has been investigated. There will need to be more attention given to whether gender bias matters in these environmental influences and to whether or to what degree test developers should account for or avoid gender bias in task selection.

Future research might consider at what ages these issues are most important. Structural equation modelling might better identify significant environmental and biological factors, and the critical task demands that contribute to the emergent GMA across the lifespan (Figure 1). Indeed, new longitudinal research might clarify the predictive power of motor assessments and even test the assumptive relative predominance of biological and environmental influences through development.

In summary, this contemporary model of GMA contrasts to earlier conceptions. We define GMA as a fluid, emergent capacity to learn, control and perform motor skills across the lifespan. It is a unidimensional construct that emerges from the interacting influences of both biological and environmental factors with task demands (not an unchanging, innate entity). This capability is inferred from the performance of movements skills or tasks (locomotor, object control, body management skills), and strengthened by movement skill foundations (such as, flexibility, balance, reaction time, strength, muscle power, etc.). All of these skills and foundation elements are trainable and mutually facilitate improved performance - these aspects are neither fixed, unchanging, nor insular in their effect. Such an integrated construct is in opposition to the hitherto dominance of specificity of abilities in motor performance (Fleishman, 1964; Henry, 1961, 1968).

References

Abbasi, I. N. (2014). Socio-cultural barriers to attaining recommended levels of physical activity among females: A review of literature. *Quest*, *66*(4), 448-467. doi:10.1080/00336297.2014.955118.

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Arlington, VA: American Psychiatric Publishing.

Bachman, J. C. (1961). Motor learning and performance as related to age and sex in two measures of balance coordination. *The Research Quarterly*, *32*(2), 123-137.

Baker, J. (2003). Early Specialization in Youth Sport: a requirement for adult expertise? *High Ability Studies*, *14*(1), 85-94. doi:10.1080/1303200009352

Baker, J., Cobley, S., & Fraser -Thomas, J. (2009). Wh specialization? Not much! *High Ability Studies*, *20*(1), 77-89. doi:10.1080/13598130902860507

Benenson, J. F., Liroff, E. R., Pascal, S. J., & Cioppa, G. D. (1997). Propulsion: A behavioural expression of masculinity. *British Journal of Developmental Psychology*, *15*(1), 37-50.

Berger, R. (1962). Effect of varied weight training programs on strength. *Research Quarterly. American Association for Health, Physical Education and Recreation*, *33*(2), 168-181.

Brace, D. K. (1930). *Measuring motor ability*. New York: A S Barnes.

Broadhead, G., Maruyama, G., & Bruininks, R. (1985). Examining differentiation in motor proficiency through exploratory and confirmatory factor analysis. *Motor development: Current selected research*, *1*, 167-179.

Bruininks, R. H. (1978). *Bruininks-Oseretsky Test of Motor Proficiency: Examiner's manual*. Circle Pines MN: American Guidance Service.

Bruininks, R. H., & Bruininks, B. D. (2005). *Bruininks-Oseretsky Test of Motor Proficiency: Examiner's manual* (2 ed.). Windsor UK: NFER-Nelson.

Bürgi, F., Meyer, U., Niederer, I., Ebenegger, V., Marques-Vidal, P., Granacher, U., . . . Puder, J. J. (2010). Socio-cultural determinants of adiposity and physical activity in preschool children: A cross-sectional study. *BMC Public Health, 10*(1), 733-733. doi:10.1186/1471-2458-10-733

Burton, A. W., & Rodgerson, R. W. (2001). New perspectives on the assessment of movement skills and motor abilities. *Adapted Physical Activity Quarterly, 18*(4), 347-365.

Caperchione, C. M., Kolt, G. S., Tennent, R., & Mummery, W. K. (2011). Physical activity behaviours of culturally and linguistically diverse (CALD) women living in Australia: A qualitative study of socio-cultural influences. *BMC Public Health, 11*(1), 26-26. doi:10.1186/1471-2458-11-26

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies,* . New York, NY, USA: Cambridge University Press.

Coakley, J. J., & Pike, E. (2014). Sports in society: Issues and controversies.

Cozens, F. W. (1929). *The Measurement of General Athletic Ability in College Men*: University of Oregon

Cratty, B. J. (1966). A Three Level Theory of Perceptual-Motor Behavior. *Quest, 6*(1), 3-9.

Cumbee, F. (1954). A factorial analysis of motor coordination. *Research Quarterly, 25*, 412-428.

Cureton, T. K. (1947). *Physical fitness appraisal and guidance.* St Louis: Mosby.

Deflandre, A., Lorant, J., Gavarry, O., & Falgairette, G. (2001). Determinants of physical activity and physical and sports activities in French school children. *Perceptual and Motor Skills, 92*(2), 399-414. doi:10.2466/pms.2001.92.2.399.

Dewey, D., & Kaplan, B. (1994). Suptyping of developmental motor deficits. *Developmental Neuropsychology*, *10*(3), 265-284.

Dobbins, D. A., & Rarick, G. L. (1975). Structural similarity of the motor domain of normal and educable retarded boys. *Research Quarterly*. *American Alliance for Health, Physical Education and Recreation, 46*(4), 447-456.

Drowatzky, J. N., & Zuccato, F. C. (1967). Interrelationships between selected measures of static and dynamic balance. *The Research Quarterly, 38*(3), 509-510.

Fields, A. (2013). Discovering Statistics Using IBM SPSS Statistics (4th Ed). Thousand Oaks, SA:Sage Publications

Fleishman, E. A. (1964). *The structure and measurement of physical fitness*. Englewood Cliffs, NJ: Prentice Hall.

Fleishman, E. A. (1972). On the relation between abilities, learning, and human performance. *American Psychologist*, *27*(11), 1017.

Gardner, H. E (1999). *Intelligence reframed: Multiple intelligences for the 21st century*. NY: Basic Books.

Geuze, R. H., & Kalverboer, A. F. (1987). Inconsistency and adaptation in timing of clumsy children. *Journal of Human Movement Studies, 13*, 421-432.

Geuze, R. H., & Kalverboer, A. F. (1994). Tapping a rhythm: A problem of timing for children who are clumsy and dyslexic? *Adapted Physical Activity Quarterly, 11*(2), 203-213.

Goncalves, H., Hallal, P., Amorim, T., Araujo, C., & Menezes, A. (2007). Sociocultural factors and physical activity level in early adolescence. *Revista Panamericana De Salud Publica-Pan American Journal of Public Health*, 22(4), 246-253.

Gubbay, S. S. (1975). *The Clumsy Child*. London: W.B. Saunders.

Gubbay, S. S. (1975). *The Clumsy Child: A Study of Developmental Apraxic and Agnostic Ataxia*. London: W.B. Saunders.

Guilford, J. P. (1958). A System of the Psychomotor Abilities *The American Journal of Psychology*, *71*(1), 164-174. doi:10.2307/1419204

Hands, B., & Larkin, D. (2001). Using the Rasch measurement model to investigate the construct of motor ability in young children. *Journal of Applied Measurement, 2*(2), 101-120.

Hands, B., Larkin, D., & Rose, E. (2013). The psychometric properties of the McCarron Assessment of Neuromuscular Development as a longitudinal measure with Australian youth. *Human movement science, 32*(0), 485-497. doi:http://dx.doi.org/10.1016/j.humov.2013.02.007

Hands, B., Licari, M., & Piek, J. (2015). A review of five tests to identify motor coordination difficulties in young adults. *Research in developmental disabilities, 41*, 40-51.

Hempel, W. E., & Fleishman, E. A. (1955). Factor analysis of physical proficiency and manipulative skill. *Journal of Applied Psychology*, *39*, 12-16.

Henderson, S. & Sugden, D. (1992). *Movement Assessment Battery for Children: Manual*. San Antonio, TX: Psychological Corporation.

Henderson, S., Sugden, D., & Barnett, A.L (2007). *Movement Assessment Battery for Children-2: Examiner's Manual*. London, UK;Pearson Assessment.

Henry, F. M. (1961). Reaction time-movement time correlations. *Perceptual and Motor Skills, 12*, 63-66.

Henry, F. M. (1968). Specificity vs generality in learning motor skill. In M. J. Safrit & G. S. Kenyon (Eds.), *Classical studies on physical activity* (pp. 328-331). Englewood Cliffs, NJ: Prentice-Hall.

Hoare, D. (1994). Subtypes of developmental coordination disorder. *Adapted Physical Activity Quarterly, 11*(2), 158-169.

Holliday, R. (2006). Epigenetics: a historical overview. *Epigenetics, 1*(2), 76-80.

Ibrahim, H., Heard, N. P., & Blanksby, B. (2011). Exploring the general motor ability construct. *Perceptual and Motor Skills, 113*(2), 491-508.

Keele, S. W., Ivry, R. I., & Pokorny, R. A. (1987). Force control and its relation to timing. *Journal of Motor Behavior, 19*(1), 96-114.

Kelso, J. S. (1997). *Dynamic patterns: The self-organization of brain and behavior*: MIT press.

Lämmle, L., Tittlbach, S., Oberger, J., Worth, A., & Bös, K. (2010). A two-level model of motor performance ability. *Journal of Exercise Science & Fitness, 8*(1), 41-49.

Larkin, D., Hands, B., Kendall, G., Parker, H., & Sloan, N. (2007). *Are we measuring Motor Ability?* Paper presented at the Progress in Motor Control V1, Santos, Brazil.

Larson, L. A. (1941). A factor analysis of motor ability variables and tests, with tests for college men. *Research Quarterly, 12*, 499-517.

Lawrence Rarick, G., & Alan Dobbins, D. (1975). A motor performance typology of boys and girls in the age range 6 to 10 years. *Journal of Motor Behavior, 7*(1), 37-43.

McCarron, L. T. (1997). *MAND McCarron Assessment of Neuromuscular Development*. Dallas, TX: Common Market Press.

McCloy, C. H. (1934). The measurement of general motor capacity and general motor ability. *Research Quarterly, 5*(Supp1).

McCloy, C. H. (1940). A preliminary study of factors in motor educability. *Research Quarterly. American Association for Health, Physical Education and Recreation, 11*(2), 28-39.

Meyers, C., & Dingman, H. F. (1960). The structure of abilities at the preschool ages: hypothesized domains. *Psychological Bulletin, 57*(6), 514.

Newell, K. M. (1986). Constraints on the development of coordination. In M. G. Wade & H. T. A. Whiting (Eds.), *Motor development in children: Aspects of coordination and control* (pp. 341-360). Boston MA: Martinus Nijhoff.Parizkova, J. (1996). *Nutrition, physical activity, and health in early life*: CRC Press Bocan Raton, Fla.

Parker, H., Larkin, D., & Wade, M. G. (1997). Are timing problems subgroup specific in children with Developmental Coordination Disorder? *The Australian Educational and Developmental Psychologist, 14*(1), 35-42.

Ramos Salas, X., Raine, K., Vallianatos, H., & Spence, J. C. (2016). Socio-cultural determinants of physical activity among Latin American immigrant women in Alberta, Canada, *Journal of International Migration and Integration, 17*(4), 1231-1250. doi:10.1007/s12134-015-0460-y.

Rarick, G. L., Dobbins, D. A., & Broadhead, G. D. (1976). *The motor domain and its correlates in educationally handicapped children*. Englewood Cliffs, NJ: Prentice-Hall.

Salvia, J., & Ysseldyke, J. E. (1988). *Assesment in special and remedial education*: Houghton Mifflin.

Schellekens, J., Scholten, C., & Krboer, A. (1983). Visually guided hand movements in children with minor neurological dysfunction: Response time and movement organization. *Journal of Child Psychology and Psychiatry, 24*(1), 89-102.

Schmidt, R. A. (1991). *Motor learning and performance: From principles to practice*. Champaign, IL: Human Kinetics Publishers.

Schmidt, R. A. & Lee, T. D. (1999). *Motor control and learning: A behavioural emphasis* (3rd ed.). Champaig, IL: Human Kinetics.

Seashore, R. H. (1930). Individual differences in motor skills. *The Journal of General Psychology*, *3*(1), 38-66.

Silva, P. A., Birkbeck, J., Russell, D. G., & Wilson, J. (1984). Some biological, developmental, and social correlates of gross and fine motor performance in Dunedin Seven Year Olds. *Journal of Human Movement Studies, 10*, 35-51.

Spearman. C. (1904). General Intelligence, Objectively determined and measured. *American Journal of Psychology, 15*, 201-293.

Spearman, C., & Jones, L. L. (1950). *Human ability*. London, UK: Macmillan.

Sporns, O., & Edelman, G. M. (1993). Solving Bernstein's problem: A proposal for the development of coordinated movement by selection. *Child development, 64*(4), 960-981.

Sugden, D. A., & Keogh, J. F. (1990). *Problems in Movement Skill Development*. Columbia, SC: University of Columbia Press.

Sveistrup, H., Burtner, P. A., & Woollacott, M. H. (1992). Two motor control approaches that may help to identify and teach children with motor impairments. *Pediatric Exercise Science, 4*(3), 249-269.

Tabatabainia, M., Ziviani, J., & Maas, F. (1995). Construct validity of the Bruininks-Oseretsky test of motor proficiency and the Peabody Developmental Motor Scales. *Australian Occupational Therapy Journal 42*, 3-13.

Thelen, E. (1995). Motor development: A new synthesis. *American Psychologist, 50*(2), 79.

Thurstone, L., & Thurstone, T. G. (1941). *Factorial studies of intelligence*.

Thurstone, L. L. (1946). Theories of intelligence. *Scientific Monthly, New York.*

Ulrich, D. (2000). *Test of Gross Motor Development* (2nd ed.). Austin TX: Pro-ed.

Ulrich, D. A. (1985). *Test of Gross Motor Development*. Austin, TX: Pro-ED.

Wendler, A. J. (1938). A critical analysis of test elements used in physical education. *Research Quarterly. American Association for Health and Physical Education, 9*(1), 64-76.

Whitely, S. E. (1983). Construct validity: Construct representation versus nomothetic span. *Psychological Bulletin, 93*(1), 179-197.

Wiersma, L. D. (2000). Risks and Benefits of Youth Sport Specialization: Perspectives and Recommendations. *Pediatric Exercise Science, 12*(1), 13-22. doi:10.1123/pes.12.1.13

Williams, H. G., Woollacott, M. H., & Ivry, R. (1992). Timing and motor control in clumsy children. *Journal of Motor Behavior, 24*(2), 165-172.

Wright, B., & Masters, G. N. (1982). *Rating Scale Analysis*. Chicago, MI: MESA Press.

Wulf, G., & Lewthwaite, R. (2009). Conceptions of ability affect motor learning. *Journal of Motor Behavior, 41*(5), 461-467. doi:http://dx.doi.org/10.3200/35-08-083

Zwicker JG, Yoon SW, MacKay M, Petrie-Thomas, J., Rogers, M., Synnes, A. R. (2013). Perinatal and neonatal predictors of developmental coordination disorder in very low birthweight children. *Archives of Disease in Childhood, 98*:118-122. http://dx.doi.org/10.1136/archdischild-2012-302268.