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The General Motor Ability Hypothesis: An old idea revisited

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The General Motor Ability Hypothesis: An Old Idea Revisited

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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

1 similarly low correlations. Henry (1968) concluded that even abilities like coordination and
2 agility, considered by some as 'generic' in successful athletic performance, were specific to
3 particular motor tasks. Thus, a newer view prevailed that individuals proficient in performing a
4 wide range of movement skills possessed many different, specific abilities, and that patterns of
5 specific abilities involved in successful motor performances differed among different individuals.

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

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

30 31 **Statistical Evidence for a GMA**

1
2 To date, first order factor analyses of motor performance data derived from multiple tasks
3 have seemed to provide the principal support for the existence of multiple motor abilities, distinct
4 from a global motor ability, since, as noted above, only weak correlations between separate motor
5 skills have been found. Further, separately identified abilities have appeared to have little in
6 common (though the reasons provided for these distinctions may be unrelated to whether a GMA
7 exists). However, test item selection in these assessment instruments has been determined
8 arbitrarily and neither rooted in historical testing protocols nor framed around any theoretical
9 model of motor ability. Additionally, within these tools, measurement and analysis methods may
10 vary, including, for example, the use of exploratory versus confirmatory factor analytic procedures
11 (Fields, 2013). Further, differing ages and sex of participants in psychometric investigations of
12 these tools have precluded valid comparisons of factor analytic results between studies. Finally,
13 Whitely (1983) reminded us that the low correlation values between tasks may reflect many
14 influences or be related to error variance. When the same data are analysed using different
15 techniques, the resultant factors may vary; and identifying and naming specific abilities associated
16 with test item clusters is highly dependent on the content of arbitrarily chosen test items (Carroll,
17 1993). Thus, researchers have given different labels to what appear to be similar factors; and,
18 across separate studies, the same task may even be linked with different attributes. For example,
19 Cozens (1929) classified the vertical jump as a measure of leg strength whereas Larson (1941)
20 labelled it as a measure of motor explosiveness. Similarly, Cozens proposed that the bar snap was
21 a measure of body coordination, agility and control, while Larson described it as a measure of
22 dynamic strength. The use of different labels attached to presumed underlying motor abilities
23 persists today in commonly used motor assessments. For example, the MAND (McCarron, 1997)
24 associates standing jump with explosive power whereas the MABC (Henderson, Sugden &
25 Barnett, 2007) uses jumping in squares for dynamic balance. Similarly, the jump and clap task is
26 considered to measure dynamic balance (Henderson & Sugden, 1992) or bilateral coordination
27 (Bruininks, 1978)

28 Regarding low inter-correlations between specific tasks, other factors concerned with
29 constraints from task demands, person or environment characteristics, may decrease apparent
30 associations (Newell, 1986). For instance, the interacting factors that may reduce these
31 correlations include differing levels of skills development or prior experience with tasks at hand

1 (task learning); different motor demands in a given task performance such as dexterity versus
2 strength (task characteristics); different motoric demands from the dynamic challenges of a given
3 performance environment (open or closed tasks); or different mobility task demands (stability
4 versus in motion); biological development and task difficulty; the physiological status of the
5 individual (physically fit or sedentary); and skill measures with a limited score range. Without
6 fully accounting for the effect of such extraneous factors in patterns of inter-correlation between
7 skills, their true associations with one another may be misrepresented.

8 **Factor Analysis**

9 Factor analysis seeks to identify a smaller number of underlying variables or factors from
10 large data sets by examining the inter-correlations. While the patterns of inter-correlations
11 between specific different motor skills may be weak, this alone does not dismiss a strong
12 underlying association between specific motor skills and the existence of a single general or global
13 motor ability. Even though most factor analyses of motor skill test batteries have been applied in
14 order to identify specific motor skills that accounted for a performance, several researchers have
15 identified a general coordination factor in their first order analyses. Wendler (1938), Larson
16 (1941), Cureton (1947), Cumbee (1954), Hempel and Fleishman (1955), and Rarick and Dobbins
17 (1975) all identified a general factor they named Gross Body Coordination that emphasised
18 movement of the whole body and often included the concept of agility. Later, Fleishman (1964,
19 p. 35) explained that Gross Body Coordination involved central nervous system activity and was
20 “the ability to integrate the separate abilities in a complex task”. Previously, McCloy (1940, p.46)
21 coined the term ‘motor educability’ measured within his neuromotor test of “general innate motor
22 capacity” (p.46), arguing that this score represented the capacity to learn new motor skills.
23 Bruininks (1978) found more than half of the test items in the Bruininks-Oseretsky Test of Motor
24 Proficiency (BOTMP) loaded 0.3 or more on one general factor which accounted for
25 approximately 70% of the total common factor item variance. He interpreted it as ‘general motor
26 development’. Similarly, the factor analysis of the BOTMP scores from children aged 4.5 - 5.5
27 years by Tabatabainia, Ziviani and Maas (1995) revealed one factor, labelled ‘general motor
28 proficiency’ that accounted for 48.3% of the common variance. In the revised BOT-2, inter-
29 correlation coefficients ranged between 0.54 and 0.80 between the Total Motor Composite and
30 Subtest Scale Scores (Bruininks & Bruininks, 2005). A factor analysis of skills in the Test of
31 Gross Motor Development (TGMD; Ulrich, 1985, 2000) identified one factor on which all skills

1 loaded with an eigenvalue of 3.80. The authors assumed the skills measured a single construct
2 known as gross motor ability.

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

18 **Cluster Analysis**

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

27 **Item Response Theory Analysis**

28 Item Response Theory (IRT) analyses test the fit of a given data set to an a priori
29 expectation model and then position both test items and individual persons on a common
30 unidimensional and additive scale. When the data fit the model, items are located along the
31 measurement continuum according to the difficulty they present to the person, and persons are

1 positioned according to the ability demonstrated with regard to those test items (Wright & Masters,
2 1982). With IRT, evidence of a GMA would be demonstrated if various items representing a range
3 of different motor skills fit a unidimensional model. Bruininks (1978) first used IRT to equate
4 items across different samples to validate the conversion of raw scores to standard scores and
5 estimate total subset scores based on performance on a few BOTMP items. When the BOT-2
6 (Bruininks & Bruininks, 2005) was developed, item fit involving all candidate items was examined
7 using IRT (specifically Rasch analysis). Only those items that fit the model, that is, measured a
8 single dimension were retained in the final version. Hands and Larkin (2001) used the Extended
9 Logistic Model of Rasch to analyze data for 24 motor skills performed by 332 five and six year
10 old children. Given significant gender differences in motor performance, gender-separate analyses
11 were conducted and revealed two different, unidimensional, scales of motor ability for boys and
12 girls. Just as Thurstone (1946, p. 110) acknowledged that a second order general intelligence
13 capacity - the “central energizing factor which promotes the activity of all these special abilities”
14 - could exist, the same can be said for a general motor ability capacity, based on positive raw
15 correlation coefficients, and analyses of data derived from a range of motor skills using more
16 sophisticated procedures.

17 **Models of a GMA**

18
19 Some theorists describe motor ability as a hierarchical or a multi-tiered construct (Cratty
20 1966; Schmidt, 1991). Cratty (1966) envisaged a three-tiered framework of factors contributing
21 to perceptual-motor behaviour. General cognitive dispositions such as aspiration level, arousal,
22 ability to analyse a task, and task persistence were seen as relatively stable qualities at the highest
23 tier, all of which might be influenced by the person’s experience. At the second tier were
24 perceptual-motor ability traits that have often been identified in factorial studies, such as static
25 strength and extent flexibility. At the base of these three tiers was a GMA. Later, Schmidt (1991)
26 proposed a similar three-tiered framework, presented as an inverse of Cratty’s model, in which he
27 used the term ‘super-ability’ to describe the overriding, global structure of motor behaviour. The
28 second tier involved specific motor abilities (such as reaction time, finger dexterity) which made
29 up different, but possibly overlapping, subsets of abilities contributing to the varied motor tasks
30 placed at the base layer.

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

15 **GMA: A Unidimensional Construct**

16
 17 With this research backdrop, we present a contemporary model of GMA, based on
 18 Newell’s Theory of Constraints (1986), that is hypothesised as a fluid, emergent capacity to learn,
 19 control and perform motor skills across the lifespan (Figure 1). We conceive it as a unidimensional,
 20 rather than multi-layered, construct that emerges from the interacting influences of both biological
 21 and environmental factors with task demands. GMA is not directly measurable, but must be
 22 inferred from the performance of movements skills or tasks (locomotor, object control, body
 23 management skills), and strengthened by movement skill foundations (such as, flexibility, balance,
 24 reaction time, strength, muscle power etc.).

25 [Insert Figure 1 and Figure 2 here]

26 Figure 2 illustrates the key principles affecting GMA across the lifespan. Postnatally,
 27 GMA changes and adapts in response to the interaction of personal, developmental and
 28 environmental influences. It, therefore, is not a fixed, inherited capacity, but a capability that both
 29 increases and then declines across time. The initial level of motor ability in infancy and early
 30 childhood arises from the primary influence of genetics – integrity of the neurobiological system
 31 foundations, and gender of the individual. As the child develops, there is increasing influence from

1 environmental facilitators (such as opportunity, practice, socio-cultural norms) and
2 organismic/personal factors (such as age, motivation, resilience, physical fitness, previous
3 learning). Optimally, GMA increases throughout adolescence, peaks in adulthood and then
4 declines as one ages beyond mid-adulthood, again as a function of personal, biological and
5 environmental (illness, disease, etc) factors. We elaborate on these factors below.

6 **Biological Foundation**

7 **Integrity of biological foundations.** Neurobiology is certainly implicated in motor ability.
8 According to Fleishman (1964), the notion of a general ability to coordinate movement implies
9 central nervous system involvement that is independent of particular body parts or muscle groups.
10 Biological underpinnings of motor ability, therefore, likely relate to the integrity of integrated
11 motor, vestibular, kinaesthetic and somatic systems (Gubbay, 1975; Sveistrup, Burtner, &
12 Woollacott, 1992), and such heritable morphological characteristics as body type (Parizkova,
13 1996). Evidence of relative timing among groups of cortical neurons during movement tasks
14 suggests that temporal stability or rhythmicity may be a key component of skilled motor
15 performance (Kelso, 1997) and the ability to move quickly in response to differing situations may
16 contribute to, or reflect, a person's overall GMA. Should any neurological subsystem for
17 movement control be slightly impaired or undeveloped, motor performance would be
18 compromised. Gubbay (1975, p. 3) noted "the smooth functioning of the motor system not only
19 depends upon its anatomical intactness, but also upon the integrity of all other central structures
20 which act upon or influence motor function." When children with Developmental Coordination
21 Disorder (DCD) were compared to their same-age peers, they were found to have more variable
22 muscle sequencing and timing (Geuze & Kalverboer, 1987;1994; Williams, Woollacott, & Ivry,
23 1992), poor precision of muscle activity (Parker, Larkin, & Wade, 1997), or poor force control
24 (Keele, Ivry, & Pokorny, 1987), and they were slower to respond in a series of single and repetitive
25 tasks (Schellekens, Scholten, & Krboer, 1983). Any disturbance of these integrated systems, such
26 as a premature birth or post-natal steroid exposure (Zwicker et al., 2013), no matter how minor,
27 may result in a reduced ability to perform skilful movement and may be described as motor
28 impairment or a lower motor ability.

29 **Sex.** The differential effect of sex on motor performance is often ignored in motor skills
30 research. Yet, repeated studies have identified different biological structures between males and
31 females in motor skill assessments. Rarick and Dobbins (1975) extracted differing factor structures

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

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

1 (1985) used exploratory factor analyses to demonstrate an increasing differentiation of motor
2 proficiency with age; and they found that one factor accounted for 40% of the variance in 3.5 to
3 6.5-year-olds but accounted for only 20% of the variance in older children. Environmental
4 influences may help account for the identification of the more specific abilities identified in older
5 children and adults (Fleishman, 1964, 1972), but differentiated capabilities are also a function of
6 brain development. Burton and Rodgeron (2001) reviewed a number of developmental studies
7 that collectively indicated greater differentiation, or specificity, in motor abilities from childhood
8 to adulthood.

9

10 **Environmental Influences**

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

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

1 support given by parents, teachers (school physical education), coaches and peers for physical
2 activity opportunities.

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

18 **Implications of a GMA Theory**

19 If individual variance in motor competence is best explained by a GMA, it will be
20 important to continue to try to understand the degree to which generic ability may be genetic,
21 developed and changed through environmental influences (Wulf & Lewthwaite, 2009) or
22 epigenetic in a combination of both (Holliday, 2006). Current views of the basis of motor ability
23 favor neither exclusive hereditary (innate) nor environmental factors. Thelen's (1995) neonate and
24 infant stepping studies demonstrated that growth (fat deposition on limbs) and the associated
25 biomechanical constraints in air or water environments was a primary constraint on stepping
26 behaviors. Her findings opposed the primacy of innate neural maturation as the sole explanation
27 for the disappearance of this reflexive behaviour by around six weeks of age, and supported
28 omnipresent environmental influences. The closely intertwined nature of biological and
29 environmental influences is illustrated by ways in which environmental opportunities to fine tune
30 the system through practice and experience stimulate both biological growth and the development
31 of neural pathways thereby further enhancing motor performance and ongoing engagement with

1 the environment. Our proposed model of GMA across the lifespan (see Figure 2) addresses the
2 changing predominance of interactions between hereditary and environmental influences that
3 typically occur at different points of the lifespan. Interestingly, even beliefs about motor ability
4 play a role in motor learning capability. Wulf and Lewthwaite (2009) showed that, for young
5 adults, learning a motor skill was enhanced by reinforcing beliefs that a person's motor ability was
6 'learnable' and not a fixed, inherent capacity. Accordingly, the key tenets of our GMA model are
7 that GMA is:

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

18

19 **Implications for practice or motor interventions**

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

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

1 developmental stage these should be considered when designing and delivering interventions and
2 training programs, including positive social support by teachers, parents, peers, and coaches.

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4 **Implications for motor assessment**

5 There is no generally accepted, unifying theoretical framework (or taxonomy) of the motor
6 skill domain. Terminology and labels for abilities vary and are not interchangeable between
7 researchers and practitioners. Models of motor abilities often identify hierarchical relationships
8 between the underpinning foundation abilities and the overarching motor ability construct,
9 meaning that the motor ability construct still relies on multidimensional test batteries with a variety
10 of measurement tasks that have often been arbitrarily chosen or based on historical precedence
11 (Burton & Rogerson, 2001). Contemporary neuromotor tests, such as the Bruininks Oseretsky
12 Test, 2nd edition (Bruininks & Bruininks, 2005), the Movement Assessment Battery for Children,
13 2nd edition (Henderson, Sugden et al., 2007), and the McCarron Assessment of Neuromuscular
14 Development (McCarron, 1997) all include batteries of tasks sub-grouped into several skill
15 domains or skill clusters, such as balance, dexterity, ball skills, or strength. Commonly, these skill
16 ‘domains’ are justified as the underlying abilities of motor performance even though a
17 standardized, single, summary motor score is derived from the separate item scores. In deriving
18 this summary score, contemporary tests implicitly subscribe to the notion of a common motor
19 factor, or general motor ability, even while they emphasize subskills. Many of these motor tests
20 have been criticised for lacking theoretical support (Salvia & Ysseldyke, 1988) or for extrapolating
21 dimensions of motor ability in adult samples to children or vice versa, both without empirical
22 validation (Hands, Licari, & Piek, 2015; Lämmle, Tittlbach, Oberger, Worth, & Bös, 2010).

23 Re-conceptualizing motor assessment through a GMA theory re-emphasizes the
24 importance of an underlying GMA and leads to valid, reliable motor testing that is grounded in
25 theory, developmentally appropriate, and gender specific. If motor ability is primarily
26 unidimensional, test items should be selected differentially in accordance with those that are suited
27 to the age and sex of the person tested, and the overall summary score should have particular
28 meaning. Any profile of specific abilities should be seen as secondary to a GMA, and subskills
29 would likely be most relevant for older, rather than younger, persons. The meaning of a given test
30 item or understanding of what it is measuring should be theoretically as well as empirically

1 derived. There should be clarity to what a summary or composite score actually represents, as a
2 “level of motor development” (Ulrich, 2000), motor learning capability or global motor ability.
3 Attention should also be paid to what motor test items have the most relevance and importance for
4 each phase of the lifespan. For example, limb coordination may matter most in infancy, while the
5 mastery of locomotor, body management, and object control tasks matter more in childhood,
6 power and speed become important in adolescence whereas balance and flexibility could be most
7 important in older adults. Accordingly, we propose the development of a Lifespan Motor Ability
8 Scale based on Item Response Theory, as presented in Figure 3. This statistical model, depicts
9 how task difficulty would change for any one skill with each developmental phase. The example
10 demonstrates how such task variations, in this case catching, are not merely lock-stepped with
11 increasing age. Motor testing should select task variations according to difficulty level as
12 established by IRT approaches.

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[Insert Figure 3 here]

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16 **Implications for research**

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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 Rodgeron’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

1 specific motor abilities for a particular skill; yet this approach might facilitate consensus among
2 researchers as to how to properly label specific important abilities. For example, is muscle power
3 or strength and coordination most critical to the standing broad jump?

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

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

16 In summary, this contemporary model of GMA contrasts to earlier conceptions. We
17 define GMA as a fluid, emergent capacity to learn, control and perform motor skills across the
18 lifespan. It is a unidimensional construct that emerges from the interacting influences of both
19 biological and environmental factors with task demands (not an unchanging, innate entity). This
20 capability is inferred from the performance of movements skills or tasks (locomotor, object
21 control, body management skills), and strengthened by movement skill foundations (such as,
22 flexibility, balance, reaction time, strength, muscle power, etc.). All of these skills and foundation
23 elements are trainable and mutually facilitate improved performance - these aspects are neither
24 fixed, unchanging, nor insular in their effect. Such an integrated construct is in opposition to the
25 hitherto dominance of specificity of abilities in motor performance (Fleishman, 1964; Henry,
26 1961, 1968).

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