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Article · September 2020

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Reconceptualizing and Operationalizing Seefeldt's Proficiency Barrier: Applications and Future Directions

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Abstract

In 1980, Seefeldt introduced the concept of a motor skill “proficiency barrier” that provides a conceptual basis for understanding the importance of a motor skill barrier as it relates to critical public health initiatives. While the intent of Seefeldt's proficiency barrier hypothesis had great potential to advance the field of motor development, the notion of a proficiency barrier was not empirically tested. Instead, this concept lay dormant for several decades. The purpose of this paper was to expand upon Seefeldt's proficiency barrier concept in greater detail by addressing the following questions: (1) what constitutes a motor proficiency barrier? (2) how do we assess/measure the existence of a proficiency barrier? and (3) how do we break through the proficiency barrier in order to maximize the likelihood of participation in health-enhancing levels of physical activity later on in life? We conclude with a future research suggestion to explore the existence of the proficiency barrier.

Key Points

A proficiency barrier may impede the developmental transition between stability and mobility.

Most children will develop a minimal level of competency with motor skills (e.g., stability patterns) with free play and little instruction. To break through the proficiency barrier, children need structured movement experiences early to learn mobility patterns. We suggest mobility patterns are culturally promoted whereas stability patterns are more species-typical.

We challenge the readership to explore empirically testing the existence of the proficiency barrier.

Ali Brian and Nancy Getchell are co-lead authors with equal contributions

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1 Introduction

Over the past 30 years, an alarming upward trend in obesity rates has occurred, almost tripling since 1975 [1]. During the same period, daily physical activity rates have dropped substantially and sedentary behavior has increased [2]. Equally alarming, but far less recognized, is a secular decline in motor competence levels in young children over the past several decades. For example, Brian and colleagues [3] reported

that 77% of a sample of children ages 3–5 years from across the US were at or below the 25%tile with approximately 30% of children demonstrating profound developmental delays (<5%tile) in their gross motor skills. However, policymakers and practitioners have been slow to make the connection between physical activity and motor competence. We argue, the failure to make this link occurs by addressing the need to increase physical activity in isolation from the context of activity from a holistic, developmental perspective (i.e., how well they move) [4, 5].

In essence, only focusing on promoting a greater “amount of time” in moderate-to-vigorous physical activity (MVPA) without regard to *how* individuals move when they are active and *why* they are motivated to sustain PA behaviors is problematic when considering that child development is a complex and dynamic process [5–8]. Recent longitudinal and other meta-analysis data speak to the potential long-term impact that developing motor competence has on PA [9, 10], multiple aspects of health-related fitness [11–13], weight status [12, 14, 15], and other critical aspects of child development [7, 16, 17]. Thus, failure to acquire ‘adequate’ levels of competence in a broad variety of motor skills in childhood could partially explain and parallel the secular decline in physical activity and fitness, and the rise in obesity levels across childhood, adolescence, and into adulthood. Unfortunately, the term “adequate” currently has not been empirically defined. However, in 1980, Seefeldt introduced the concept of a motor skill “proficiency barrier” that provides a conceptual basis for understanding the importance of sufficient motor competence levels as an integral part of physical activity as it relates to critical public health initiatives.

1.1 History and Potential Importance of a Proficiency Barrier?

Seefeldt [18] proposed that motor development occurred via progression through developmental periods that were represented in a conceptual model (see Fig. 1). Level 1 consists of reflexes (e.g., palmar grasp, Babinski, startle) and postural reactions generally situated in infancy (e.g., rolling, sitting up, pulling up to stand) and is followed by a period framed within early childhood (i.e., 2–5 years old) that is linked to the acquisition of ‘fundamental motor skills’ (e.g., running, jumping, throwing, catching), which are precursors to activities that require more skill-specific adaptations for games and sports (e.g., baseball, soccer, tennis). Seefeldt placed a proficiency barrier between the fundamental motor skill development period in early childhood and transitional skills during middle childhood into adulthood. Transitional skills assist with the transition from basic patterns to context-specific use of skills in games and activities such as lead up activities (throw-and-catch volleyball), small-sided games [small dimensions, slower speeds, fewer players], and

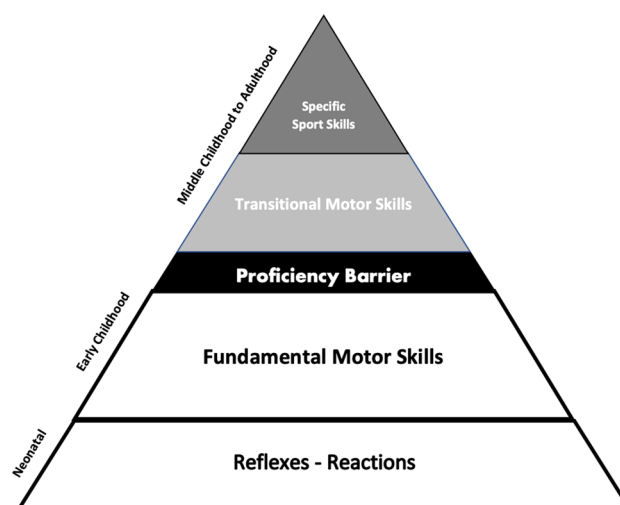


Fig. 1 Seefeldt’s original conception of the proficiency barrier. Adapted with permission from Seefeldt V. Developmental motor patterns: implications for elementary school physical education. Psychology of motor behavior and sport—1979 [18]

non-sport specific skills (e.g., jump rope). Seefeldt noted, “The proficiency barrier is placed between the ‘fundamental’ and ‘transitional’ skills because our work has shown that children who are *deprived of learning the fundamental skills have difficulty when they attempt to learn the transitional motor skills* (pp. 316)” (italics added). In 1986, Haubenstricker and Seefeldt suggested the proficiency barrier may also have implications later in childhood with respect to participation in activities that require vigorous physical effort as successful and sustained participation would demand competency in various motor skills inherently integrated in a broad spectrum of activities (e.g., games and sports) [19]. While the intent of Seefeldt’s proficiency barrier hypothesis had great potential to advance the field of motor development, the notion of a proficiency barrier was not empirically tested. Instead, this concept lay dormant for several decades. Thus, one focus of this paper will be to operationalize (i.e., to put something to use or into operation) the proficiency barrier, specifically focusing on its potential importance in the public health domain and as it relates to other aspects of child development.

Malina [20] recently revisited Seefeldt’s concept using the proficiency barrier as one of the top ten questions that researchers should address to combat the continued trend in childhood obesity. Malina suggested that there may be a level of movement competence above which a child would be more likely to engage in various physical activities, including sport, and below which a child would be less likely to engage in such activities,” (pp 164). Malina followed with, “Is there a critical level of movement proficiency (competence) that facilitates physical activity and sport participation (in children and adolescents)?” (pp 164).

Two recent studies have explored the proficiency barrier concept relating motor competence levels to aspects of health. Stodden et al. [21] tested for a proficiency barrier using a product-oriented composite skill battery including throwing and kicking speeds and jumping distance to predict normative levels (i.e., good, fair, or poor) of health-related fitness levels in young adults. Only 2.5% (2 out of 65) 18- to 25-year-old adults who were classified as “low-skilled” (i.e., the lowest 35%tile of the sample) were classified as having “good” health-related fitness ($\geq 60\%$ tile based on normative fitness data). 97.5% of participants classified as high-skilled ($> 60\%$ tile) demonstrated at least “fair” (i.e., $\geq 36\%$ tile) fitness. While the findings did not definitively identify a proficiency barrier, the very low percentage of individuals in the lowest third of motor competence that demonstrated fair fitness levels (2.5%) is consistent with predicted outcomes of a proficiency barrier.

Similar results were found in a more recent study where researchers tested a specific barrier of “at risk for developmental delay” ($< 25\%$ tile based on a normative assessment of twelve motor skills) and examined its capability to predict the likelihood that children in middle and late childhood (7–12 years old) would participate in at least 60 min of moderate-to-vigorous physical activity per day [22]. Children with more advanced skill levels (i.e., $> 65\%$ tile of motor competence) were 2.5 times more likely to meet the MVPA guideline than lower skilled children (i.e., $< 65\%$ tile). Specific to the proficiency barrier concept, $< 12\%$ (29 out of 248) of children at or below the 25% tile met the MVPA guidelines.

Data from these two studies, although limited in their capability to definitively identify a proficiency barrier, offer compelling insight and a novel strategy to investigate the impact of motor skill development on various health-related variables across childhood. Additional research is needed to systematically examine attributes of skill development that not only can be linked to further skill advancement and a potential proficiency barrier, but also may be linked to other critical child development variables (e.g., self-concept, weight status). The purpose of this paper was to expand upon Seefeldt's proficiency barrier concept by reconceptualizing the notion of a proficiency barrier and attempting to operationalize it with a focus on the public health and child development domains. Specifically, we address the following questions: (1) what constitutes a motor proficiency barrier? (2) how do we assess/measure the existence of a proficiency barrier?; and (3) how do we break through the proficiency barrier in order to maximize the likelihood of participation in health-enhancing levels of physical activity later on in life?

2 Question 1: What Constitutes a Proficiency Barrier?

One demarcation point that may define a proficiency barrier, or a dichotomous separation in motor competency levels, may exist at the point at which children transition their movement emphasis from movement stability (i.e., prioritizing the maintenance of a stable, upright posture) to mobility (i.e., maximizing movement capability and performance) in a variety of intra-task developmental sequences [23]. That is, a proficiency barrier may exist at a point of transition along a developmental trajectory between movement pattern coordination strategies designed to facilitate an underlying goal of either stability or mobility. Promoting increased mobility (vs. stability) inherently involves many critical underlying aspects of learning and development including perceptuomotor integration, motivation, practice, intrinsic and augmented feedback, self-perceptions, as well as a myriad of potential goals (e.g., environment exploration for an infant, increased speed of movement, increased center of mass [COM] translation capability to transfer energy through the kinetic link system for object projection tasks). If a proficiency barrier exists, children will not progress within a number of different specific skill developmental sequences (i.e., demonstrate higher developmental levels in different action components over time that promote mobility). In other words, children continue to demonstrate lower developmental levels in multiple skills over a long period of time.

However, while our suggestion that mobility vs. stability may be one critical differentiation point in skill development, it is not our intent to minimize the inherent complexities involved in the development of motor coordination and control, nor is it our intent to provide a one-size fits all approach to operationalize a dichotomous skill competence barrier. We have chosen to use the locomotor skill of walking as an exemplar to illustrate the stability vs. mobility idea, as it is the first independent bipedal locomotor skill acquired throughout the lifespan, while also noting that many different locomotor skills (e.g., running, hopping, skipping, etc.) demonstrate similar developmental progressions in stability to mobility coordination strategies. From a holistic perspective, the development to more advanced levels of walking promotes increased physical activity via the expansion of children's capabilities for exploration of their physical environment. For a new walker, controlling postural stability in order to maintain balance is the most difficult challenge to overcome in order to move independently on two feet. Walking requires the ability to continuously move the center of mass forward over an alternating base of support (i.e., alternating

balance on one foot). If movers cannot maintain an upright posture while repetitively shifting the COM forward (i.e., cyclical dynamic balance) over their base of support while responding to reactive forces generated by their own movements and changing environmental conditions, they will not effectively and efficiently maximize forward movement. A “stability” strategy of limb configurations maximizes overall body stability (e.g., shorter stride, wider base of support, arms in a high guard position and lower center of gravity), which in turn minimizes the odds of falling while limiting walking speed [24–26]. A stability strategy reflects the goal of maximizing a stable, upright posture at the expense of walking speed. Many locomotor skills in their earliest forms, such as hopping and galloping, share similar upper and lower body configurations that optimize stability. The transition to a more advanced and efficient mobility strategy, facilitated by practice, maximizes COM forward movement and minimizes horizontal COM translation with longer strides and oppositional coordination with the upper extremities. Similar advancements in coordination strategies for other locomotor skills are required to be successful in many activities that require advanced mobility patterns and represent Seefeldt’s notion of advancement across the proficiency barrier to more transitional skills.

2.1 Are Skills Species-Typical or Culturally Promoted?: A Preliminary Discussion

Historically, it was assumed that the process of motor skill acquisition in infancy and childhood occurred automatically through maturation of the central nervous system [27–29]. According to this maturational perspective, early motor skills emerged over time in a species-specific, orderly progression with limited impact from the environment during infancy and childhood. McGraw’s 1935 longitudinal study on Johnny and Jimmy examined the role of heredity and environment on motor behavior, which challenged the maturational perspective [30]. McGraw distinguished between species-typical (i.e., phylogenetic) motor skills, those naturally occurring skills essential for basic functioning and survival, and culturally promoted (i.e., ontogenetic) skills, whose development was based on individual experiences. This early motor development research shed light on the importance of *experience* in motor skill acquisition. Further, it arguably set the stage for a shift away from a maturational perspective, and also indirectly provides the rationale for a proficiency barrier framework. Children will often be able to perform many motor skills in a rudimentary form (i.e., fundamental) without practice or instruction, using body configurations that increase body stability. However, culturally promoted skills, often used in sport contexts, require individuals to generate force (run faster, jump higher, kick

or throw a ball farther or faster). In essence, the notion that instruction and practice under different environmental conditions is necessary to advance from stability to mobility strategies speaks to the idea of species-typical versus culturally promoted skill development.

2.2 Stability Strategies may be More Species-Typical or Innate; Mobility Strategies, More Culturally Promoted, or Learned

The suggestion that the adoption of stability strategies may be more species-typical (innate to and more consistent across humans) than culturally promoted (learned through experiences and more varied across humans) supports the idea that most children develop stability strategies without much external instructional support (e.g., [31]; see Sect. 4.2 for more detail). Following the logic of Bernstein [32], early learners often constrain or ‘freeze’ joint movement to limit the number of moving segments (degrees of freedom) to accomplish a movement goal. This freezing of limb movements can be observed in early forms of many motor skills as a means of simplifying movement control, but limits the system’s capability and flexibility to respond to perturbations that challenge stability and balance [33]. Continuing from our previous example, early walkers constrain degrees of freedom by taking short steps that minimize lower extremity joint ranges of motion and trunk rotation, which maximizes the period of double foot support. Furthermore, a “high guard” position (e.g., holding arms out at shoulder level) of the upper extremities is maintained in order to minimize lateral excursions of the COM, concurrently decreasing the need for large reactive forces created during forward movement with each step [25, 34, 35]. The initial coordinative pattern results in a variable COM translation path in both the anterior–posterior and medial–lateral directions. Using a stability strategy for locomotion contributes to the capability to maintain an upright posture while moving, but also drastically limits the overall velocity (i.e., both speed and directional goals) of locomotion. When addressing the progression of different locomotor patterns across childhood, the transition from a quadri- (i.e., crawling) to bi-pedal pattern (walking), and then from walking to running represent potential different transition “barriers” that may be linked to physical activity levels and other child development factors.

Similar stability strategies that constrain degrees of freedom also can be identified within foundational forms of several locomotor skills, such as running [36, 37], hopping [38, 39], and jumping [40, 41] (Figs. 2, 3, 4). Specifically, the use of the high guard arm position is again utilized in less advanced patterns of both hopping and running to maintain postural stability at the expense of performance (i.e., translation of the body in the anterior direction). Even when the high guard arm position (i.e., increased shoulder abduction)

SEQUENCE	ACTION
LEG ACTION	
Step 1	Minimal flight. The running step is short and flat-footed. On the recovery swing forward, the leg is rather stiff.
Step 2	Crossover swing. The stride is long, and the knee of the recovery leg flexes to at least a right angle. The leg action, though, has lateral movements wherein the legs swing out and in during the recovery.
Step 3	Direct projection. The stride is long, and the recovery leg tucks to swing forward. The legs project directly backward on takeoff and swing directly forward for the touchdown.
ARM ACTION	
Step 1	High or middle guard. Both of the arms are held up between waist and shoulder level and move very little as the legs stride forward and back.
Step 2	Bilateral arm swing. The arms swing but are coupled, moving forward and backward together.
Step 3	Opposition, oblique. The arms drive forward in the opposition pattern, each moving forward and backward with the opposite leg, so that one arm is moving forward while the other is moving backward. The arms, though, swing across the chest or out to the side in a plane oblique to the plane of movement.
Step 4	Opposition, sagittal. The arms swing forward and back in the opposition pattern and stay nearly in the sagittal (or forward-backward) plane of movement.

Fig. 2 Developmental sequences for running. Adapted with permission from Haywood and Getchell [50]

SEQUENCE	ACTION
Step 1	Vertical component of force may be greater than horizontal; resulting jump is then upward rather than forward. Arms move backward, acting as brakes to stop the momentum of the trunk as the legs extend in front of the center of mass.
Step 2	The arms move in an anterior-posterior direction during the preparatory phase but move sideward (winging action) during the in-flight phase. The knees and hips flex and extend more fully than in step 1. The angle of takeoff is still markedly greater than 45°. The landing is made with the center of gravity above the base of support, with the thighs perpendicular to the surface rather than parallel as in the reaching position of step 4.
Step 3	The arms swing backward and then forward during the preparatory phase. The knees and hips flex fully before takeoff. On takeoff the arms extend and move forward but do not exceed the height of the head. The knee extension may be complete, but the takeoff angle is still greater than 45°. On landing, the thigh is still less than parallel to the surface, and the center of gravity is near the base of support when viewed from the frontal plane.
Step 4	The arms extend vigorously forward and upward on takeoff, reaching full extension above the head at liftoff. The hips and knees extend fully, and the takeoff angle is 45° or less. In preparation for landing, the arms are brought downward and the legs are thrust forward until the thighs are parallel to the surface. The center of gravity is far behind the base of support on foot contact, but at the moment of contact the knees are flexed and the arms are thrust forward to maintain the momentum to carry the center of gravity beyond the feet.

Note: Degrees are measured from horizontal.

Fig. 3 Total body developmental sequences for Jumping Adapted with permission from Haywood and Getchell [50]. Also adapted with permission from Clark and Phillips [40]

SEQUENCE	ACTION
LEG ACTION	
Step 1	Momentary flight. The support knee and hip quickly flex, pulling (instead of projecting) the foot from the floor. The flight is momentary. Only one or two hops can be achieved. The swing leg is lifted high and held in an inactive position to the side or in front of the body.
Step 2	Fall and catch; swing leg inactive. Forward body lean allows minimal knee and ankle extension to help the body "fall" forward of the support foot, then quickly catch itself again. The swing leg is inactive. Repeat hops are now possible.
Step 3	Projected takeoff; swing leg assists. Perceptible pretakeoff extension occurs in the hip, knee, and ankle in the support leg. There is little or no delay in changing from knee and ankle flexion on landing to extension before takeoff. The swing leg now pumps up and down to assist in projection. The range of the swing is insufficient to carry it behind the support leg when viewed from the side.
Step 4	Projection delay; swing leg leads. The weight of the child on landing is now smoothly transferred along the foot to the ball before the knee and ankle extend to takeoff. The support leg nearly reaches full extension on the takeoff. The swing leg now leads the upward-forward movement of the takeoff phase, while the support leg is still rotating over the ball of the foot. The range of the pumping action in the swing leg increases so that it passes behind the support leg when viewed from the side.
ARM ACTION	
Step 1	Bilateral inactive. The arms are held bilaterally, usually high and out to the side, although other positions behind or in front of the body may occur. Any arm action is usually slight and not consistent.
Step 2	Bilateral reactive. Arms swing upward briefly, then are medially rotated at the shoulder in a winging movement before takeoff. It appears that this movement is in reaction to loss of balance.
Step 3	Bilateral assist. The arms pump up and down together, usually in front of the line of the trunk. Any downward and backward motion of the arms occurs after takeoff. The arms may move parallel to each other or be held at different levels as they move up and down.
Step 4	Semi-opposition. The arm on the side opposite the swing leg swings forward with that leg and back as the leg moves down. The position of the other arm is variable, often staying in front of the body or to the side.
Step 5	Opposing assist. The arm opposite the swing leg moves forward and upward in synchrony with the forward and upward movement of that leg. The other arm moves in the direction opposite to the action of the swing leg. The range of movement in the arm action may be minimal unless the task requires speed or distance.

Fig. 4 Hopping developmental sequences Adapted with permission from Robertson and Halverson [80]. Also adapted with permission from Robertson and Halverson [44]

is no longer used in walking, this strategy is employed when individuals push the transitional skill boundary towards greater mobility in more complex skills (e.g., running) [42,

43]. High guard also is employed in less advanced hopping, in which only the stance leg action promotes forward movement of the COM at the earliest developmental levels [44].

These coordination patterns optimize stability in that they are reactionary and reflexive movements that serve to maintain upright posture. As they appear to be ubiquitous across locomotor skills in early childhood, we suggest they are species-typical in that overt instruction is not demanded for the demonstration of these rudimentary movement patterns.

Advancing from more rudimentary coordination patterns to those that maximize mobility requires the shift from primarily reactionary and stability-based movements to intentional performance-enhancing movements. Transitioning to culturally promoted movement patterns requires that individuals explore the boundaries of their stability strategies and may initially promote a high degree of variability in movement patterns and performance. This exploration occurs by voluntarily testing movement capabilities via increasing effort and force production in upper and lower extremity movements that serve to project the body. Increased force production may increase the angular velocity and range of motion across multiple joints, leading to changes in the speed and/or directionality of the overall movement. These initial attempts to increase effort and the overall resultant speed of movement may occur in lower and/or upper extremity and can promote a general destabilization of the existing rudimentary coordination patterns. This destabilization leads to highly variable limb movements and potentially decreased stability (i.e., loss of balance).

Decreased stability, in the transition to a more highly advanced coordination pattern, is a necessary function of development noted by an increase in the overall output of the system (e.g., movement speed) and may result in the individual falling or completely stopping the movement pattern temporarily so as not to fall. A risk vs. reward potential in destabilizing movement is necessary to advance to a different coordination pattern and next level of movement performance. For example, when hoppers shift away from stability coordination patterns, increases in force production serve as a catalyst to “release” constrained limbs and reorganize the system into a new coordination pattern (e.g., arms pump in opposition or semi-opposition to each other vs. a high guard position). Somewhat similar in the development of hopping is a coordination pattern between the non-support leg and arm movements that demonstrate an opposing anterior–posterior coordination pattern with the non-support leg and the contralateral upper extremity. The emergence of a new coordination pattern is generally associated with an increased speed of COM translation (i.e., body projection) and produces a system that is able to hop faster and/or higher with a greater flight phase or hopping distance [45]. In a less advanced coordination pattern the non-support leg is suspended in front of the body (i.e., relatively fixed hip flexion and knee flexion) while the arms demonstrate a variable coordination pattern (e.g., high guard or bilateral winging movements). These less advanced movements

do not promote any additional projection capabilities in the anterior/posterior plane and thus, the stance leg is the only aspect of movement promoting forward movement of the system. Both of these less advanced movements demonstrate a lack of rhythmical opposing contralateral coordination patterns (i.e., anterior and posterior directions) that would promote mobility. As the phenomenon of stability to mobility coordination strategies is demonstrated across all bipedal locomotor skills, we propose it as a testable proficiency barrier in this broad category of skill development.

Interestingly, some of these same stability/mobility transitional movement features also are present in some levels in object control skills that demonstrate increased COM translation across advancing developmental levels. For example, in throwing, increased COM translation speed parallels increases in step, trunk, humerus, and forearm development levels [46, 47], as well as increases in ball speed. When contrasting the most rudimentary coordination pattern of throwing to the most advanced pattern, a clear distinction can be made with respect to the transition from a bilateral dominated stability stance and limited upper extremity movements (i.e., no step, limited trunk rotation and limited movements) to a unilateral stance and where the COM reaches anterior translation speeds of greater than 2 m/s [46]. In addition, highly advanced throwing also demonstrates bilateral opposition in the upper extremities that is associated with high velocity trunk and arm segmental speeds as the entire body mass is projected forward while simultaneously rotating upon a fixed unilateral stance position. Thus, the transition from a stability posture (i.e., bilateral stance with limited trunk and upper extremity speed and range of motion movements) to a highly dynamic unilateral stance with upper extremity bilateral opposition mirrors the transition from stability to mobility movement strategies demonstrated in locomotor skills. The same general developmental continuum also is seen in the skill of kicking [48].

2.3 The Stability–Mobility Trade Off: What Facilitates Motor Skill Acquisition and Transition from Rudimentary, Stability Strategies to More Advanced Mobility Strategies?

The development of complex coordination patterns across time does not occur in a linear and straightforward manner as noted in the above-mentioned classifications of stability vs. mobility movement descriptions. In order to advance movement patterns across the barrier from stability-promoting, species-typical patterns to more culturally promoted patterns that support enhanced mobility, multiple environmental stimuli are required [49]. The emergence of more highly advanced coordination patterns evolves across many hours and potentially years of practice and diverse learning experiences that are facilitated by various forms of instruction

(e.g., teaching and modeling) and feedback (e.g., intrinsic and augmented). However, the relative simplicity of the aforementioned anatomical and biomechanical stability vs. mobility explanations aligns with the dichotomous explanation of an overall movement system “barrier” that must be overcome in order to advance to higher levels of coordination and performance that will serve to promote lifelong participation in the plethora of activities that involve these skills.

3 Question 2: How Do We Assess/Measure the Existence of a Proficiency Barrier?

One potential strategy to measure the stability versus mobility profile would be to use the component developmental sequences approach [50] (Table 1, Figs. 2, 3, 4). The suggested use of developmental sequences, which outline ordinal levels of movement for specific body components, can delineate a specific skill barrier (i.e., a barrier being a measurable dichotomous distinction) from a qualitative perspective (e.g., the transition from a level 1 to a level 2 may be a measurable mobility/stability transition point) and speaks to a dynamical systems framework with distinct order parameter differentiation [51]. Further, it can help identify a general proficiency barrier when children demonstrate lower developmental levels in a wide variety of skills. Other process-oriented assessments may also be useful in this manner as there are specific critical elements that may speak to a specific transition point as well. Specifically, the Test of Gross Motor Development (TGMD) or others like it (e.g., Get Skilled Get Active [52]) assessments have “present or absent” critical elements. Measuring skill levels with assessments that demonstrate specific qualitative coordination

pattern differences (see Table 1, Figs. 2, 3, 4) can then promote the creation of stability versus mobility profiles to test against the likelihood of achieving health-enhancing levels of physical activity, fitness, weight status, and participation in sports and games.

Product-oriented assessments would inherently have greater difficulty differentiating a mobility/stability barrier as they provide continuous/scaled data. However, this process could entail comparing product scores against a process-oriented assessment for comparison or prediction [54]. Process- and product-oriented assessments that have normative levels also provide another means to note a potential proficiency barrier in their classification of risk for developmental delay (e.g., < 15th or < 25th percentiles) that may not be linked to specific skill movement patterns, yet provide comprehensive skill level classifications. This process would be more difficult in the sense that these levels are variable depending on how percentiles are used for classification purposes (e.g., different states use different “at risk” levels or cultural differences). Thus, our initial thought of using developmental sequences provides a means to non-arbitrarily test for a potential barrier in both general and specific skills as well as within established test batteries that can be linked, not only to critical public health outcomes, but also to other product-oriented skill classifications that would align with this dichotomous divide in qualitative coordination patterns. We have provided a table to provide examples of how stability and mobility profiles may be assessed (see Table 1, Figs. 2, 3, 4). Coincidentally, both papers that have initially addressed the possibility of a barrier [21, 22] have used process (i.e., TGMD normative levels associated with “at risk” for developmental delay) as well as product scores (throw/kick speed and jump distance) to “test the waters” of the proficiency barrier as they relate to health-related outcomes.

Table 1 Suggested profiles for stability and mobility

Action	Developmental sequences		TGMD-3	
	Stability	Mobility	Stability	Mobility
Run			0–7	8
Leg	1 or 2	3		
Arms	1, 2, or 3	4		
Jump				
Total body	1, 2	3, 4	0–5	6–8 arms do not have to fully extend
Hop			0–7	8
Leg	1, 2,	3, 4		
Arm	1, 2, 3, 4	5		

See Figs. 2, 3 and 4 for a description of each movement. For a description of the Test of Gross Motor Development-3 (TGMD-3) items, please refer to the TGMD-3 manual [53]

4 Question 3: How Do We Break Through the Proficiency Barrier in Order to Maximize the Likelihood of Participation in Health-Enhancing Levels of Physical Activity Later on in Life?

4.1 Shifting from Stability to Mobility Does Not Occur ‘Naturally’ but Requires Practice and Experience

Motor development research during early childhood casts light on the importance of experience in acquiring more advanced motor skills and sets the stage to shift away from a maturational perspective towards an approach that better supports the role of learning in skill development (i.e., culturally promoted experience). Newell’s constraints model

[55] provides conceptual framework whereby motor skill development results from repetitive and progressive practice in various environments over time; these experiences interact along a growth and maturation continuum resulting in advancing movement patterns. Although the role of growth and maturation in motor skill development plays a specific role in skill development across childhood and adolescence, the age-related, but not age-dependent, notion of development [56] specifically embodies the impact of experience (i.e., ontogeny) to move beyond the proficiency barrier. Consider the argument by Langendorfer and Robertson [31] that rudimentary levels of the developmental sequence for throwing may be species-typical, in that most individuals could reach this level of throwing with relatively minimal practice. They reasoned that most individuals required a considerable amount of practice to reach the most advanced developmental levels of over arm throwing, thus making advanced skill development culturally promoted. Cast in a more general way, the acquisition of some fundamental motor skills such as walking and throwing require minimal practice to demonstrate rudimentary forms of the motor skill (e.g., adopting a stability coordination strategy). These skills can be considered species-typical in that they exist independent of country or culture [57]. Soon after acquiring these rudimentary, stability phase movement patterns, specific experiences guide further improvement in skill (e.g., shifting from stability to mobility strategies) and demonstration of advanced levels requires significant amounts of practice based on the context in which the skill will be used [54]. Thus, in order to break through a proficiency barrier, children need to engage in practice and skill-specific experiences consistently throughout childhood in a positive, yet challenging learning environment [58–62].

4.2 Intervention Works Very Well When it Starts During the Early Years

Mobility strategies are learned and occur through context-specific *experiences and practice only*, which is critical for promoting the shift from stability to mobility movement strategies [54, 63–65]. Requiring context-specific practice to learn motor skills is contrary to the common standard of practice suggesting 30–60 min of daily free play (recess) provides adequate experiences and opportunities for young children to develop fundamental motor skills [66, 67]. However, we do not wish to minimize the importance of free play as it provides children with the opportunity to explore their environment, socialize with peers, and a myriad of other important developmental attributes. Thus, we suggest providing both structured and context-specific unstructured opportunities for children to learn to move. Unfortunately, results from emerging data shows that more children are at risk for developmental delay or actually demonstrate delay

in many fundamental motor skills [3, 68–70]. When exposed to developmentally-appropriate instruction context-specific physical activities, young children can continually advance their motor skills with a dose of as little as six hours across six weeks [54, 64, 71]. Thus, from a constraints perspective, providing continued and sequential mobility-specific instruction for a variety of skills and adequate supplemental experiences in the early years will promote the advancement of movement skills so children have a better chance of breaking through the proficiency barrier.

Specifically for locomotor skills, instruction and experiences that target the exploitation of neuromuscular mechanisms (i.e., stretch–shortening cycle) that promote the rapid transition from eccentric to concentric contractions in the lower extremity kinetic chain (i.e., plyometric movements) will promote COM translation in both horizontal and vertical dimensions of movement (i.e., flight phase and increased speed of COM translations). Promoting instruction and environmental design that emphasizes speed of movement (e.g., faster, quicker) and/or larger excursions of the COM in various locomotor activities (e.g., bigger, higher) as opposed to focusing on instruction that only emphasizes positioning and movements that attempt to mimic what advanced level coordination patterns “look like” (e.g., body segment positional instruction that attempts to specify opposition in both the lower and upper extremities) promotes moving beyond stability and maintaining balance to moving the entire body in a way that facilitates an unstable new coordination pattern. This enhanced strategy for instruction has been noted in developmental literature to promote advanced skill levels (e.g., promote increased force or effort) [48, 72] as well as progressions of locomotor movement drills (i.e., plyometrics) in sport performance-based training [73]. The emphasis on effort-based movement promotion also is embedded within the context of many games and activities (e.g., races or timed performance) and can be easily promoted via appropriate environmental design of tasks.

Attempts to perform at a more advanced level with an emphasis on higher effort trigger the exploitation of multiple biomechanical and neuromuscular function principles. First, linear (COM) and rotational energy (across joints) is generated and transferred through multiple body segments via a closed kinetic chain mechanism across multiple segments with increased force production [48]. Increased force production is promoted via the exploitation of elastic muscle/connective tissue contributions within the context of rapid eccentric/concentric muscle actions where energy is initially generated during preparatory eccentric movements (e.g., preparatory jumping movements of arms and the lowering of the COM) and is transferred via subsequent concentric movements. Highly skilled individuals, as compared to less skilled individuals, effectively incorporate more segments into their movement patterns and utilize kinetic chain

principles more effectively to maximize energy transfer [46, 47, 74] and increase performance.

In addition, promoting this global transition to more explosive faster movements may trigger, without explicit instruction, perturbations in upper extremity actions that also serve to destabilize the “stability” coordination dynamics between the upper and lower extremities and promote more advanced “mobility” coordination strategies between the upper and lower extremities (i.e., beginning opposition between the upper and lower extremity movements). While this strategy may initially promote a loss of balance and stability in bipedal posture as well as the coordination between the upper and lower extremities (e.g., loss of balance and decreased performance), this perturbation in system dynamics is necessary to initiate the transition to more advanced mobility strategies. This strategy to promote a more advanced coordination pattern, and ultimately increased performance, is akin to identifying and exploiting a control parameter (i.e., terminology used in motor control language) that functions to destabilize existing coordination patterns (i.e., the current order parameter) and foster the emergence of a new pattern. It is important to understand and effectively translate these principles into instruction across multiple developmental periods (i.e., across childhood and adolescence), but with developmentally appropriate instructional and training strategies. For example, instructional information and intervention settings will look quite different in early childhood practices, with fundamental motor skill terminology (i.e., step with opposition, move to the beat) being used, as opposed to adolescence where long-term athletic development (LTAD) language (e.g., dynamic stretching [stretch while moving], plyometrics [explosive, fast, jumping movements]) may be more appropriate in a sport setting. Overall, the skills promoted in early childhood and advanced training for sport are similar (i.e., various forms of jumping, hopping, skipping, etc.) with a similar intent of promoting enhanced mobility strategies (i.e., advanced skill patterns and technique) and ultimately, performance.

5 A Shift from a Proficiency Barrier to Barriers Towards Proficiency: Future Directions and Recommendations

What underlying changes occur as a function of practice? Seefeldt [18] suggested a “period of readiness” or sensitivity to practice in children between the ages of 4 and 7 years old. Theoretically, gross motor intervention should be more effective during the early years than during middle-to-late childhood. However, what is occurring, neurologically, that supports ease of learning during early years as opposed to greater challenges with initial skill learning/skill improvement in later years? We recognize the extent to which

degrees of neuroplasticity support ease and depth of skill learning is relatively unknown. Thus, we recommend future investigations explore the role that neuroplasticity plays in motor skill development and also the differential effects of gross motor intervention across childhood and adolescence.

Future examinations should build upon the preliminary studies that provide evidence to support that children with motor skill levels below the proficiency barrier are indeed less likely to be physically active [22], physically fit [15, 21] and maintain a healthy weight [14, 15]. As more children are demonstrating low levels of motor competence [3] that is linked to mobility strategies of movement and developmental delay, future intervention studies should also examine if there is a specific dose of intervention/practice needed to overcome potential delay and advance beyond a potential proficiency barrier. Thus, future research should examine the mediational role of growth and maturation in overcoming a proficiency barrier [75].

Rudimentary or intermediate motor skill levels which fall below the proficiency barrier may show differential effects for children who mature later than those with normal or early maturation. Finally, future studies should *continue* to test the potential existence of a proficiency barrier through multiple measures and across time, both by cohort and longitudinal observational studies. Recently, Getchell et al. [76] offered suggestions for conducting rigorous motor development studies. Among those suggestions were cross-sequential designs where researchers can assess initial age, longitudinal effects, and do so across multiple age-bands. Within a cross-sequential design, we suggest using dependent measures such as meeting physical activity recommendations, frequency of sport, type of sport (e.g., recreational vs competitive), and game engagement, to test how stability versus mobility profiles predict the likelihood of engagement and/or meeting recommendations.

Future research also should test the proficiency barrier hypotheses across a wide-variety of age, sex, gender, ethnicity, race, location, socioeconomic status, disability-type, and body weight status to capture the greatest amount of generalizability. Overall, providing a framework to explore testing of the proficiency barrier hypothesis is important to effectively measure the potential impact that a proficiency barrier may have on multiple public health issues and other developmental outcomes.

6 Implications for Practice and Motor Learning

Improving skill development through practice during the early years will promote a stronger foundation of skill upon which children can continue positive developmental trajectories of skill learning. Conversely, those who do not have

these early experiences are not necessarily barred from acquiring motor skills. However, individuals without early experiences with fundamental motor skills may require much more practice than a child with early experiences in order to achieve an advanced skill level. In addition, without early, developmentally-appropriate experiences, children would be limited in their ability to explore alternative, context-specific movement solutions that enhance mobility in more complex (e.g., sport related) movement settings. As a result, they maintain their stability strategy as the safest and most secure manner to perform the desired skill, ultimately limiting their ability to successfully participate in activities that require advanced skill performance.

The requirement for significantly more practice to transfer from rudimentary skill level to advanced motor skill learning amplifies the notion that a proficiency barrier is difficult to overcome. Notably, the increasing amount of practice necessary for advanced motor skill learning needs to occur, as currently there is little emphasis on structured motor experiences during the early years, reduced time in free play, and also decreasing number of practice opportunities for novice performers since many sport-related programs become more competitive with advanced age groups. In essence, if a child lacks the skills to successfully participate in games, sports and recreational activities in the early years, opportunities to learn skills dwindle across time, making it more difficult to overcome this barrier to lifelong participation.

7 Conclusion

The impasse that we have reached in the obesity epidemic, as well as declines in gross motor development and fitness, and surging rates of sedentary behaviors requires that we must look for new ways to understand what drives the problem. We can no longer suggest simplistic solutions (continuing to ignore the role of motor development) for this complex issue (e.g., increase physical activity to decrease adipose tissue), particularly in light of the fact that global rates of obesity continue to grow. Motor skill development will play a critical role in both the quality and quantity of physical activity individuals engage in across the lifespan. To this end, we posit that a proficiency barrier is an important consideration for addressing the development of physical activity behaviors and that children must transcend this barrier in multiple skills in order to move in more energetically demanding patterns [77, 78] inherent in a variety of activities across childhood and adolescence.

In conclusion, we reconceptualized and expanded upon Seefeldt's (1980) hypothetical proficiency barrier model by situating the divide between stability and mobility coordination patterns that relate not only to skill development and performance, but also to future health-related behaviors.

The early years are the ideal time for children to learn and develop a wide-variety of fundamental motor skills through structured and unstructured, developmentally-appropriate experiences in safe and positive environments. If children are successful during the early years, they will be more likely to learn advanced level, mobility-enhancing levels in a variety of motor skills. Motor skills are not birthday presents with acquisition occurring purely as the result of maturation [79]. Rather, in order to overcome a hypothesized proficiency barrier, children need to practice skill in a developmentally appropriate and mobility promoting environment, which should be specifically designed to allow for individual levels of development. The mechanism by which children transition from stability to mobility strategies is through motor skill learning and practice. We emphasize that this transition does not occur naturally, but requires skill-specific practice and experiences. Without adequate practice, secular decline in motor skill competence is imminent [3] and may lead to further secular decline in PA, fitness and increasing obesity levels. An appropriate foundation of coordination and control that facilitates successful participation in a variety of health-enhancing physical activities also serves to augment aspects of self-concept (e.g., perceived competence, self-efficacy and self-worth) that also support future development of positive trajectories of overall health and well-being.

Compliance with Ethical Standards

Conflict of interest Ali Brian, Nancy Getchell, Larissa True, An De Meester and David Stodden declare that they have no conflicts of interest relevant to the content of this review.

Funding No sources of funding were used to assist in the preparation of this article.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication All authors provided consent for publication.

Availability of data and materials Not applicable.

Code availability Not applicable.

Author contributions AB, NG, and DS wrote the first draft of the manuscript. AB, NG, DS, LT, and AD revised the original manuscript. All authors read and approved the final manuscript.

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