

Motor Development: A Perspective on the Past, the Present, and the Future

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In 1981, George Brooks provided a review of the academic discipline of physical education and its emerging subdisciplines. Forty years later, the authors review how the field has changed from the perspective of one subdiscipline, motor development. Brooks's text sets the scene with four chapters on motor development from leaders in the field, including G. Lawrence Rarick, to whom the book is dedicated. From this beginning, the paper describes the evolving scientific perspectives that have emerged since 1981. Clearly, from its past to the present, motor development as a scientific field has itself developed into a robust and important scientific area of study. The paper ends with a discussion of the grand challenges for kinesiology and motor development in the next 40 years.

Keywords: grand challenge, history, physical education, discipline

In the 1960s, the field of physical education was challenged to justify itself as a field worthy of graduate studies by James Conant (1963) in his book *The Education of American Teachers*. Around that same time period, the University of California system was requiring physical education departments, particularly at University of California, Los Angeles and Berkeley, to justify their field as an academic discipline. In 1981, George Brooks in his edited book, *Perspectives on the Academic Discipline of Physical Education*, takes on the challenge to show the scholarly aspects of physical education that represent an academic discipline. Within the book's sections on exercise physiology, biomechanics, motor development, motor behavior, sport psychology, and sociology, the chapter's authors detail an emerging corpus of scholarship. Forty years later, as we read Brooks's volume, it is clear that by the 1980s, the field of physical education had established a strong foundation of scholarship. So where has the field gone in the last 40 years, and where might we be headed in the future? It is to these questions that we turn with our focus on one area of study in the discipline, namely, the subdiscipline of motor development.

It is our thesis that the study of motor development has evolved in its focus and purpose over the last 40 years, resulting in different methodological paradigms, different research questions, and changing relative influences of other disciplines as well as other subdisciplines within kinesiology. We begin by setting the scene of the existing paradigms at the time of the Brooks book. In this we are helped by the fact that G. Lawrence (Larry) Rarick, for whom Brooks's book (1981), *Perspectives on the Academic Discipline of Physical Education*, is actually dedicated, was one of the early and influential scholars studying motor development and wrote a chapter in the book.

Motor Development: G. Lawrence Rarick

G. Lawrence Rarick did not start out to study children or their motor performance (Brooks, 1981). Quite the contrary, Rarick was

trained at the University of Iowa by C.H. McCloy and W.W. Tuttle, both interested in athletic performance and muscle physiology. Rarick's dissertation involved developing a 22-item test battery to assess the speed of athletic performance (Rarick, 1937). This work combined his interest and background in the muscle, the behavioral domain, and assessment (Park, 1997). Interest in motor development did not emerge until after World War II when he was at Boston University and assigned to teach a course in child development and to guide students with an interest in motor development (Park, 1997). Even in his work on motor development, however, Rarick was deeply influenced by his biological training. In his chapter in Brooks's book, he describes the work of embryologists, such as Coghill (1929) who studied the growth and development of the *Amblystoma*'s nervous system, as the foundation for the study of motor development (Rarick, 1981). Indeed, the sections of Rarick's chapter were organized around genetic and maturational factors; differential effects of age, sex, and maturity; physique and the development of motor abilities; ethnic and cultural factors; stability and change; and intellectual factors. Clearly, these topics fit into Rarick's (1981, p. 163) definition of motor development as a field "concerned with studying the origins and development of motor behavior in humans" or "the study of ontogenetic change in human movement." Rarick's work was representative of a period of motor development research that started after World War II and has been referred to as the "Normative/Descriptive Period" (Clark & Whittall, 1989).

Motor Development: The Perspectives of Malina, Keogh, and Broadhead

In paying tribute to Rarick, Brooks included three additional chapters on motor development by two of Rarick's former graduate students, Robert Malina and Geoff Broadhead as well as his colleague, Jack Keogh (Brooks, 1981). Together these four chapters comprised the largest section of the book.

Much like Rarick, Malina's chapter (1981) is focused on the importance of the biological processes of growth and maturation to physical performance. Factors that influence these processes and new methodological techniques are presented. Little is offered with regard to how motor skills develop except to raise the importance of

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these underlying biological processes to the study of children's motor performance.

Keogh's chapter (1981), in contrast, offered a very different world view of motor development that includes not only the physiological factors, but also the neuromuscular, perceptual-cognitive, and personal-social factors. Most of the chapter is focused on the perceptual-cognitive mechanisms underlying movement skill development. Importantly, and in contrast to Rarick and Malina, Keogh introduces the concept of a "developmental" point of view that could be applied to particular aspects of movement, such as fitness, skill, or behavior. To Keogh, "the development of movement skills . . . is a complex and dynamic process that can be characterized as the progressive achievement of movement control" (Keogh, 1981, p. 214). Whereas Rarick defined motor development as the study of ontogenetic change in human movement, Keogh's definition emphasized the development of motor skillfulness and the underlying processes that also changed over time. Keogh's approach to motor development, in contrast to Rarick's approach, exemplified the emerging "Process-Oriented Period" in the history of motor development (Clark & Whitall, 1989).

In addition to his leadership in understanding the motor development of typically developing children, Rarick made significant contributions to the study of children who were challenged both physically and mentally (cf. Rarick, 1973). In the final chapter of the motor development section, Broadhead (1981) reminds us of our educational mission and, in particular, that of adapted physical education. Several laws had been passed in the United States that mandated special services for children identified as handicapped. Rarick's research on children with Down's syndrome and with mental retardation positioned him and his colleagues to play an important role in this aspect of physical education. In this regard, the research, for example, on the benefits of regular exercise on mentally retarded or otherwise handicapped children came from a (special) education perspective rather than a motor development perspective. However, in order to comply with the laws and provide physical education for all children, a better understanding of motor development was and is essential to the design of developmentally and individually appropriate instructional programs.

Motor Development Circa 1981: Another View

While Brooks (1981) included four chapters on motor development in his book, these contributions were not fully representative of the field at that time. A few years earlier (1979), a Big Ten Committee on Institutional Cooperation conference was held that brought together a larger, more diverse group of scientists focused on motor development. In 1982, papers from this conference were published in an edited volume, *The Development of Movement Control and Co-ordination* (Kelso & Clark, 1982). This volume and the conference were intended as a sequel to Connolly's (1970) edited volume, *Mechanisms of Motor Skill Development*, which marked the start of what Clark and Whitall (1989) described as the "Process-Oriented Period" in the history of motor development. Indeed, the majority of papers in the Kelso and Clark volume took a process-oriented approach to understanding the development of control and coordination. However, the normative/descriptive period also was represented in the book with chapters on phases and stages of the fundamental motor skills (Robertson, 1982; Seefeldt & Haubenstricker, 1982). Rarick (1982), too, provided

a chapter in which he acknowledged the new process-oriented view and argued that more research was needed in this area offering several suggestions for future research.

The one paper that differed markedly from the others in this book was a paper contributed by Kugler, Kelso, and Turvey (1982) entitled "On the Control and Co-ordination of Naturally Developing Systems." This landmark paper offered an entirely different conceptualization of how motor skills develop that would come to be referred to as the "Dynamical Systems Perspective" (Clark & Whitall, 1989; Whitall, Schott, et al., 2020). The authors wrote that they "have attempted to provide a unified theoretical framework which stands accountable to the developmental problems associated with scale and dimensional changes" (Kugler et al., 1982, p. 71). The principles presented were drawn from the disciplines of philosophy, biology, engineering science, in particular nonequilibrium thermodynamics, and the ecological approach to perception and action. Briefly, Kugler et al. argued that the emergence of new movement forms could be understood by applying principles from these disciplines, namely, dynamic principles of real-time behavior to motor behavior and its development. While this paper was recognized at the time as being influential, it was a challenge to understand and apply; however, its impact on motor development research would be significant as it unfolded over the ensuing years.

The End of the Century: An Expanded View of Motor Development and More on Dynamical Systems

In 1985, there was another significant conference on motor development. Wade and Whiting cohosted a North Atlantic Treaty Organization Advanced Study Institute focused on central issues in motor development, which resulted in a two-volume collection of papers (Wade & Whiting, 1986; Whiting & Wade, 1986). Chapters in these volumes addressed a wide range of topics, including prenatal motor development, manual skill development, postural and locomotor development, atypical motor development, and cultural influences on motor development. As a North Atlantic Treaty Organization Advance Study Institute, it took place in Europe (Maastricht, The Netherlands) with about half of the invited speakers (23 out of 45, and ~100 total attendance) coming from European countries with the remaining from North America. The speakers represented a variety of disciplines with half from psychology departments followed by a quarter from physical education (later kinesiology) as the second most-common disciplines.

The first volume (Wade & Whiting, 1986) contained two papers that had a profound effect on promoting research in motor development using a dynamical systems perspective. Esther Thelen, a developmental psychologist (trained in ethology), had already started challenging the traditional neuro-maturationalist view that the infant step reflex had to disappear (become inhibited) before walking could take place (Thelen, 1983; Thelen & Fisher 1982). In her paper, Thelen (1986) elaborated on a systems model of motor development based largely on the insights of the Kugler et al. (1982) as well as other earlier and foundational papers (Bernstein, 1967; Goodwin & Cohen, 1969; Haken, 1977; Kugler et al., 1980; Prigogine, 1980). Arguing against the unidimensional development of infant walking as driven by cortical maturation (McGraw, 1940), innate spinal pattern generation (Forssberg, 1985), or cognitive development (Zelazo, 1983), Thelen laid out eight hypothetical and interactive components

necessary for independent walking, each with its own timetable of growth and development and, any one of which, given a certain environmental context, could be the final “cause” or rate limiter for an infant’s first steps.

The second influential “dynamical systems” chapter in this volume was by Karl Newell (1986), who, like Thelen, referred to the Kugler et al. (1982) paper as a challenge to a prescriptive approach to the development of motor coordination. Newell’s unique contribution was to analyze the potential constraints that bound the developing actions. Newell proposed three types of constraints that determine the resulting coordination. These constraints were identified as organismic, environmental, and task constraints.

It should be noted that Kugler (1986), too, spoke at the Maastricht conference. But clearly, his paper with Kelso and Turvey (Kugler et al., 1982) provided the initial impetus for this entirely different conceptualization of how motor skills develop, and this perspective (the dynamical systems perspective) would last for the next two decades as the dominant approach to studying motor development (Whittall, Schott, et al., 2020). Studies were designed to test dynamic principles, to search for potential rate limiting constraints, and to test perception–action linkages through affordances. It is not our intention to review the literature that supports this case here since that is available in other sources (Clark, 2017; Whittall, Schott, et al., 2020). Rather we offer two summary points. First, with the shift in paradigm came a shift in the motor skills studied. Whereas the information processing approach tended to utilize laboratory tasks (e.g., reaction time; tapping), the dynamical systems approach returned researchers to focusing on gross motor and functional skills, which had been the targets for those in the normative/descriptive period. This was necessary for those studying infants, but it also made sense for those interested in older children. Second, it would be wrong to assume that almost everyone adopted this approach. Diversity of research perspectives always exists.

In summary, after 1982, the Dynamical Systems/Perception Action Approach was influential in reconceptualizing the emergence of invariant behavioral stages or motor programs from predetermined, maturationally driven entities to task-specific stable patterns of coordination that appear and transition owing to the existence and growth of multiple organismic constraints and control systems, while being constrained by environmental and task constraints. As we argue later, this reconceptualization has not been replaced per se, but the focus of motor development research is no longer bound closely to the tenets of dynamical systems. Rather, many researchers have incorporated the concepts that emerged from this perspective; for example, stability, variability, constraints, and affordances. Those today whose research questions and methodology do not follow a dynamical systems approach will still refer to Newell’s constraints triangle and/or a systems approach to guide their research questions. Indeed, the dynamical systems period peaked in the last two decades of the 20th century (Clark, 2017).

Motor Development in the 21st Century

Two decades into the 21st century and 40 years since the publication of Brooks’s text, motor development has evolved into a robust and significant scientific field. A Google Scholar search for the words “motor development,” constrained to 1900–1981 (the year of Brooks’s publication), yielded (as of April 6, 2021) 617,000 citations. The same search, constrained from 1982 to 2021, yielded

more than triple the number of citations (1,870,000) in half as many years. As Esther Thelen (1989) wrote, motor development is an old field from which there is much to learn.

As we ask the question, “Where is the field of motor development today and where is it going in the future?” we are guided by several recent efforts to answer these questions. At the 50th anniversary of the North American Society for the Psychology of Sport and Physical Activity, two lectures—one by Anderson (2018), who described motor development in the previous decade (2007–2017), and the other by Robinson (2018), who laid out future directions for motor development research—summarize well a vision of the present and the future. Whittall, Bardid, et al. (2020), too, sought to answer these two questions as did Adolph and Hoch (2019).

To capture motor development in the first two decades of the 21st century, we will use the three themes described by Whittall, Bardid, et al. (2020), which track well with observations of Anderson (2018), Robinson (2018), and Adolph and Hoch (2019). Unlike the previous periods that emerged in succession, albeit overlapping, these three themes are relatively independent areas of study that have emerged almost simultaneously with roots in the late 1990s. The three approaches identified are *Developmental Systems*, *Developmental Motor Neuroscience*, and *Developmental Health*. While there are other approaches, these three appear to capture a large portion of the field’s current research, especially as it relates to typically developing individuals, and therefore, form the basis of our discussion of motor development in the 21st century. We have, again, endeavored not to repeat many of the examples used in other sources.

Developmental Systems Approach

This theoretical perspective owes its origins to the dynamical systems approach and the work of Thelen. It seeks to be a grand unifier for the study of human development (Blumberg et al., 2017). No one developing system (i.e., motor, cognitive, emotional, etc.) is privileged or develops without the influence of other developing systems. Development is viewed as a cascade of developing systems and subsystems that operate on different time scales but come together to meet the task needs at hand. Behaviors emerge from the many constraints surrounding the individual. They are not prescribed by a genetic blueprint. Indeed, research questions should not be about whether it is nature or nurture that is most important in understanding human development, but rather how the dynamic forces of nature and nurture come together at the moment to yield organized, purposeful behaviors.

For those researchers in motor development adopting this perspective, motor behaviors are seen as embodied, embedded, enculturated, and enabled by the environment and other developing systems (Adolph & Hoch, 2019). For decades, the changing motor skills of sitting, standing, walking, running, and hopping were studied with a telescopic perspective—focused on the developing body and its developing neuromotor system and describing the developing skill itself. But we do not develop our motor skills in isolation. As infants and young children develop their locomotor skills, for example, their minds are expanded (Anderson et al., 2013) and broadened (Campos et al., 2000). Mastering upright posture impacts the development of other systems. For example, achieving sitting and standing promotes language acquisition (Iverson, 2010; Libertus & Violi, 2016). In the preschool years, research has shown that a motor skill intervention could support the children’s self-regulation skills (Robinson et al., 2016).

The interplay between cognitive and motor development is bidirectional. Consider, for example, the motor skills of playing a musical instrument or the planning that is required to learn a motor sequence. Cognitive development influences the development of these motor skills. Research has shown that a young child's ability to learn an explicit motor sequence is influenced by that child's visual working memory (Jongbloed-Pereboom et al., 2019). Visual working memory also has been demonstrated to relate to fine motor skills in typically developing children as well as those children with movement difficulties (Rigoli et al., 2012; Rigoli et al., 2013). Motor skill performance also has been shown to influence perceptual learning; namely, practice writing (rather than typing) letters improves children's letter recognition (Longcamp et al., 2005).

For those with a Developmental Systems approach, motor development is not a singular behavioral development unconnected to the development of other behaviors. Research questions center on how the various systems and subsystems cooperate and compete to produce stability and change, which are characteristic of development. Many, but not all, adherents to this approach are developmental psychologists.

Developmental Motor Neuroscience Approach

The brain-behavior relationship and its development is the focus of many studying motor development in the 21st century. Until the 1980s, insight into the developing brain was through post-mortem studies. Yakovlev and Lecours (1967), for example, used such techniques to detail the development of myelination in the maturing brain drawing inferences to the ensuing sensory and motor development. But with technological innovations in brain imaging, "seeing" brain development and its correlated behaviors was possible. Indeed, interest in the role of the brain reflects the larger scientific interest in the human brain and its development signaled by the National Institutes of Health (NIH) declaring the last decade of the 20th century—the "decade of the brain." (Goldstein, 1994). Many methods of imaging and measuring brain function have been developed. Here we focus on two and refer the reader to Whittall, Bardid, et al. (2020) for a more comprehensive discussion.

The NIH funded an MRI study of typical brain development (Evans & Brain Development Cooperative Group, 2006) and concomitant behavioral measures in over 500 children who were followed longitudinally. This data set has been used by many researchers, a few with interests in motor development. Using these data, Pangelinan et al. (2011) found an association between motor areas of the brain and performance on a visuomotor task (i.e., the pegboard) in children 6–13 years old. Those interested in the role of brain development and musical training found the children in the NIH sample who played a musical instrument had more rapid cortical thickening in those areas of the brain associated with motor planning and coordination (Hudziak et al., 2014).

Concurrent scalp recordings (e.g., EEG) have also provided a window into ongoing neural activity as infants and children perform a motor task or perceive another performing a task. Using EEG, Cannon et al. (2016) demonstrated that the reaching experience of 9-month-old infants was strongly associated with their perception of others' reaching actions. Studies also have examined how the infant's brain changed with practice. Training prereaching 4-month-old infants with "sticky" mittens that enabled contacting and retrieving objects facilitated their perception of similar actions

as measured by the amplitude of the P400 Event-related Potential (Bakker et al., 2016).

A second approach to developmental motor neuroscience employs computational neuroscience methodologies. Scientists who adopt this approach seek to understand how the brain controls and coordinates the musculoskeletal system without using direct imaging methods but inferring how the brain works through conceptual models. Such biophysical models that control systems such as the musculoskeletal complex are then mapped onto neurophysiological processes. For example, the development of the brain-behavior relationship might be conceptualized as learning an internal model of sensorimotor relationships, such as a visuo-motor relationship or joint dynamics (Bo et al., 2006; Contreras-Vidal et al., 2005; Guarrera-Bowlby & Gentile, 2004). The juxtaposition of feedforward and feedback control within these models is reminiscent of the earlier information processing models, and they can, arguably, be considered an updated version of the earlier models.

For those who adhere to a developmental motor neuroscience approach, motor development is viewed as the development of brain-behavior relationships. Researchers ask questions not just about how the brain develops, but how it develops in tandem with the emerging motor behaviors. Of course, these questions pertain to correlations, and the subsequent effort is to test for causal relationships, such as the effect of specific experiences on the brain's development and how the brain's development influences the observed motor behavior.

Developmental Health Approach

We have labeled a third current approach to motor development research in part with the recognition that physical inactivity across the lifespan is a public health problem. For those in motor development, the developmental health approach stresses the importance of promoting and supporting the development of motor skillfulness in childhood as a pathway to a lifetime of physical activity and positive health outcomes. Researchers have studied the relationship between a child's proficiency in the fundamental motor skills, for example, and their physical fitness and physical activity (cf. Lubans et al., 2010; Utesch et al., 2019 for reviews). Some researchers have examined the relationships longitudinally (cf. Lima-Alvarez et al., 2014) and found positive relationships are maintained over a few years, and some demonstrate that low competence also is maintained over time and may well impact poor health outcomes (Fransen et al., 2014; Hands, 2008). As Harter (1978) had proposed decades ago, a child's motivation to engage in an activity is related to feelings of competence and the accuracy of their perceptions of competence.

Other research in this area has gone beyond mapping relationships to studying the impact of intervening with school-aged children and preschoolers with some success (cf. Logan et al., 2012; Morgan et al., 2013). Several studies have used longitudinal designs to track the effect of interventions on later physical activity behavior (cf. Barnett et al., 2015; Zask et al., 2012) with some positive associations.

For those whose research has taken a developmental health approach, motor development is viewed and studied as an important mediator in a lifetime of physical activity engagement. Researchers have focused, in particular, on the fundamental motor skills as important foundational skills for mastery. An extensive body of work has emerged that demonstrates the relationship between motor skill proficiency and physical activity and fitness.

(cf. Barnett et al. 2016; Utesch et al., 2019). Longitudinal and intervention research is emerging that goes beyond demonstrating relationships to establishing antecedent–consequent causality between skillfulness and physical activity engagement. The purpose behind much of this research is not in understanding how motor development occurs from a physiological or neuroscience perspective or in understanding its relationship to other areas of development (although that is starting to emerge) but in providing evidence to push policy makers into making changes that will enable more children to grow up to be healthy and active adults.

Summary

As we examined the 21st century, we described three independent approaches to research on motor development that differ in their focus, purpose, and methodology. In the 2019 fourth conference of the International Motor Development Research Consortium in Verona, Italy, researchers representing each of these approaches and from a variety of disciplines and countries were present. Our hope is that each approach will continue to flourish; but our concern is that the subdiscipline of motor development, itself, will become splintered with fewer shared conferences and fewer interactions between these three approaches (and others yet to come) in the future. Perhaps this is a natural evolution in science, but it provides a segue into the future challenges for both kinesiology and motor development.

Grand Challenges for Kinesiology and Motor Development

For Brooks in 1981, the challenge for kinesiology was to demonstrate that it was worthy of being considered an academic discipline. Today that challenge has been met. In the 40 years since the publication of Brooks's book, kinesiology has developed into a mature field of scholarship along with mature subdisciplines. As we look to the next 40 years, we extend upon our recent paper (Whittall, Bardid, et al., 2020) and that of Robinson (2018) in which suggestions for the future directions for the study of motor development were offered. In the spirit of the Brooks's book, however, here we interleave the subdiscipline of motor development with that of the other subdisciplines and the field of kinesiology as we identify the challenges, small and grand, that confront us all as we continue to “develop.”

Kinesiology: One Discipline or . . . ?

Since its beginning around the turn of the 20th century, the field has been focused on lifelong physical activity as a pathway to health (Park, 1998). Yet for decades, the field of physical education and kinesiology has been “a house divided,” as Roberta Park wrote in 1998. At first it was divided by those who sought to maintain the physical education profession and those who sought to develop the academic discipline; later it would be splintered by the multiple subdisciplines within the field. So as Brooks (1981) was celebrating the individual areas of scientific study in the discipline, others were worried that these areas of specialization were fragmenting the field and would eventually lead to its demise (Hoffman, 1985; Thomas, 1987). Indeed, even in the last few years, this concern over a splintered field persists (Lawson & Kretchmar, 2017; Newell, 2017).

Clearly, one grand challenge for the future of kinesiology and its subdisciplines is to find ways to exploit the strengths of its diversity

while remaining a unified field. In the challenges that follow, we argue, solutions will not be found within only one subdiscipline's expertise, but with the expertise brought to bear by multiple kinesiology subdisciplines. So let us rejoice in our diversity of scholarly perspectives on humans moving and join forces to solve these grand challenges.

Physical Inactivity: Move It or Lose It

Since issuing the first report, *Healthy People: The Surgeon General's Report on Health Promotion and Disease Prevention*, in 1979, the United States each decade has identified goals for a healthy nation and leading health indicators. Consistently, including the latest for 2030 (U.S. Department of Health and Human Services, n.d.), the *Healthy People* report has identified being physically active as an important national goal for a healthy nation. And yet, decade after decade, physical inactivity remains a stubborn health risk for 20–30% of the U.S. population (An et al., 2016). These trends also are reflected in our nation's children. For example, 21.6% of children between the ages of 12 and 19 years were reported to be overweight (Centers for Disease Control and Prevention, 2021). And this problem is not just in the United States, it is a global problem (World Health Organization, 2018). As a field focused on physical activity, a grand challenge for kinesiology and its subdisciplines is this pandemic of physical inactivity (Pratt et al., 2020). But how best to meet this challenge?

From the perspective of motor development, physical inactivity is viewed as a developmental problem with its roots in the activity and competence of young children. But meeting the challenge at the population-level of physical inactivity is for all the subdisciplines of kinesiology that might each play a role in solving this challenge. For example, how often do we need to exercise and what type of exercise is best for health-related fitness is addressed by those in exercise physiology? In fact, these questions are a natural fit with the descendants of Rarick and Malina. How do we motivate people to engage in physical activity and maintain their adherence to these activities is within the scope of the exercise and sport psychologists? Sociologists of sport and physical activity might help with how we should build physically active communities. Every day, physical education classes and out-of-school sport/activity settings provide the instruction and practice opportunities for children to be skilled movers. Designing curricula and optimum teaching practices are vital, and research in motor learning and control and development all contribute to our understanding of how motor skills are learned and refined so that children feel competent in moving and participating in physical activity.

A Developmental Perspective: Change Across the Lifespan

As we examine the challenge of physical inactivity, it becomes clear that this is a developmental problem. But it is not the only challenge that could benefit from taking a developmental perspective, nor the only one that applies across the entire lifespan. Much of science is about taking a “snapshot” at one moment or several moments in time. For scientists interested in understanding human behavior, a perspective that examines change over time and privileges no one time in the life course over another is critical. Compared with what we know about children and young adults, the other epochs of the lifespan are a desert, and our understanding of the relationship of an earlier behavior to a subsequent behavior has been understudied.

Longitudinal studies are one way to address the study of change over time in one's lifespan and the antecedent-consequent

relationships within our lives. By studying the same individuals across their lifespan, a true developmental picture might emerge, and that picture of the individual also needs to capture the environment within which that person is developing. However, in the extant literature there are very few longitudinal studies. One early longitudinal study was undertaken by the California Institute of Child Welfare and included the Berkeley Growth Study (Jones & Bayley, 1941), which studied the mental, motor, and physical development of individuals from birth to childhood. Later, this work would form the basis of the Bayley Scales of Infant Development (Bayley, 1969), which are still in use today (Bayley & Aylward, 2019) to assess whether infants are developing typically.

Several countries have funded longitudinal studies of their developing children. In the United Kingdom, the Avon Longitudinal Study of Parents and Children followed more than 10,000 children from birth to adulthood. This study found a relationship between children walking to school and later physical activity (van Sluijs et al., 2009) and between parents' level of physical activity in infancy and their children's physical activity at 11–12 years of age (Mattocks et al., 2008). The Finns followed more than 10,000 infants from birth to age 14 years and found that infant motor development (i.e., age of walking with support and standing without support) were predictors of higher levels of physical activity (Ridgway et al., 2009).

In the United States, many of our large longitudinal studies have been of adults as they aged. For example, the Baltimore Longitudinal Study started in 1958 (Shock, 1984), the Framingham Study started in 1948 (Dawber et al., 1963), and the Seattle Longitudinal Study in 1956 (Schaie, 1996). These extant data sets are open to researchers and offer data that could answer important questions about physical activity and inactivity. Working on these data sets could not only involve working across subdisciplines within kinesiology but also working with epidemiologists, psychologists, and statisticians, among others, to construct questions that could be answered by mining their large data sets. There might even be an opportunity to add items to their databases.

Whether it is a longitudinal study over decades or over a few years, a developmental perspective offers a view of human behavioral change. The person you are studying at any one time point in that person's lifespan has a history that influences the behavior you are studying. It is, we argue, not just the study of motor behavioral change (i.e., motor development) that benefits from a developmental perspective, but also those areas of study in motor control and learning that would benefit from understanding an individual's movement history as it mediates observed present-day motor performance.

A Cross-Cultural View—Not an Ethnocentric One

Soccer (or football, as it is called in most countries), baseball, cricket, and many other sports are culturally-promoted (Reed & Bril, 1996). As we look at human performance, we need to appreciate that what we choose to measure and what we conclude about a particular performance are situated in a cultural context. Yet the fact that we know that we have an ethnocentricity in our science is rarely acknowledged or studied rigorously. Patently, a grand challenge for kinesiology and its subdisciplines is to study human movement across cultures. What are the movement forms that are culturally promoted and how does this “promotion” occur and what might we learn from these promotional efforts?

Historically, researchers such as Gesell and colleagues (1938) developed norms that identified the ages when specific motor

behaviors appeared with the tacit assumption that these norms were for all children—worldwide. However, in a recent systematic review of the cross-cultural validity of motor development screening instruments, Mendonça et al. (2016) concluded that when these instruments are developed and standardized with U.S. and Canadian children, they are not necessarily valid in other countries. In fact, much of what appears in the literature could be characterized as WEIRD—that is, coming from Western, Educated, Industrialized, Rich, and Democratic populations (Henrich et al., 2010a, 2010b).

Within kinesiology, it is the social scientists studying sport who have long been the most attuned to the importance of cultural context and the interdependence of sport and culture (cf. Lüschen, 1967). Indeed, the last chapter of Brooks (1981) includes a discussion of sport sociology, including the promise of cross-cultural analysis (Greendorfer, 1981). Here we suggest that other subdisciplines might also consider, at the least, setting up dialogs with colleagues in kinesiological departments across the world to gain cultural insight and mutually developed strategies for answering research questions. A side effect of the COVID-19 pandemic that we are enduring as we write this paper is the worldwide increase in virtual meetings and conferences. It is clear that putting together multisite or multicountry teams of researchers is easier than in the past. Indeed, Frontiers recently opened a research topic on “promoting motor development in children in the COVID-19 era” with editors from Italy, the United States, and Finland. This challenge leads naturally to our next challenge.

Big Data and *N* of 1: The Challenge of Our Research Designs

For decades, our research designs in kinesiology mostly have been laboratory-based or small group studies in the field. Large data sets do exist in national studies as mentioned earlier; in general, however, we do not aggregate our data. To solve our grand challenges, our confidence in our findings must include diversity of culture, gender, age, religion, geographic region, cohort effects, and so on, as we mentioned earlier. Such diversity cannot happen unless we think of big data aggregations. Technically, “big data” refers to data sets that are difficult to store and to process traditionally. Big data is defined by volume, velocity, and variety and should include veracity, value, and variability (the so-called Six V's; from SAS website: https://www.sas.com/en_us/insights/big-data/what-is-big-data.html#history).

A few subdisciplines of kinesiology are already talking about big data. See, for example, big data analytics for gait biomechanics (Phinyomark et al., 2018) or the articulation of sport and big data in the sociology of sport (Millington & Millington, 2015). Others, such as exercise physiology and exercise psychology, are accustomed to handling large data sets, but here we are arguing that big data can also be gleaned from all over the country (or world), similar to the way in which the medical field has found a big data secondary use of electronic medical records (Baro et al., 2015). In motor development, Databrary (nyu.databrary.org/) is a shared repository for video and audio recordings for researchers originally in human development and learning that is funded by the NIH and National Science Foundation, as well as many other foundations. Because we now have the technology to collect and store huge data sets as well as new computational methods and statisticians able to analyze these data, the prospect of using big data analytics to answer grand challenge questions is appealing.

We envision research question-led teams of researchers across the country or world (depending on the question) that propose prospective or retrospective designs, which will answer questions that benefit from the generalizability and inclusivity that can be found using this approach. As argued by Knudson (2016), the use of big data and team science may actually play a role in integrating kinesiology sciences and work against the prevailing silo-centric specialization within the subdisciplines.

Big data is not the only challenge for research design in kinesiology. At the other end of the spectrum, there are cost and time efficiency as well as utility in using an N of 1 design where an individual is the sole unit of observation. Often these designs are undervalued and ignored as “unscientific” because they are not, or are less, generalizable, and sadly, although this is slowly changing, they are harder to publish or fund. Briefly, there are three main types: (a) case studies that are observational, identify explanations of phenomena, and generate hypotheses; (b) single-subject designs that provide a quasi-experimental approach to investigate causal relationships; and (c) N of 1 randomized trials that also test hypotheses and borrow principles from the single-subject design and randomized controlled trials (Backman & Harris, 1999). The conventional randomized controlled trial was originally designed to test genetically identical plants grown in different environments and can be applied usefully to genetically identical rats raised in different environments. It assesses what is best or common on average for a given population. In contrast, N of 1 trials assess what is best for an individual person using objective data-driven criteria (Lillie et al., 2011; Mirza et al., 2017). These designs work well in a clinical population where interventions are sought and tested (Perdices & Tate, 2009; Zhan & Ottenbacher, 2001), but they might also work well in many laboratory situations where there are independent and dependent variables that would benefit from controlling individual variability. In kinesiology, we believe they will be especially useful for those investigating interventions in typically or atypically developing children as well as aging or clinical populations, which leads to our final challenge.

Disabilities and Atypical Development: The Challenge of Inclusivity

As argued in the previous challenge, there is great individual variation in typically developing individuals. There is even more variability in populations of atypically developing children and in children or adults with acquired disabilities. Our field of academic physical education or kinesiology has been associated with preventative medicine as well as remedial medicine since its inception. In his chapter in Brooks's book, Broadhead (1981) took up the issue of those with disabilities as he described adapted physical education. But for kinesiology, it is not just physical education that studies and addresses those with disabilities. Indeed, in Clark's (2017) analysis of the extant literature in motor development from 1928 to the present, she found the terms “disorder,” “retardation,” and “assessment” appeared in the 1946–1970 period, whereas in the next decade (1971–1980), “disabilities” along with “assessment” were very common. In the first decade of the 21st century, the terms had shifted to “delay” and to specific disabilities such as developmental coordination disorder and autism. While this was a search of the literature in motor development, all subdisciplines have or should consider the research challenge of including those with disabilities and atypical development. For example, studies such as those that examine strength training (Ivey

et al., 2017) or provide body weight support (Gama et al., 2017) to those who have had a stroke demonstrate well the value of multiple subdisciplinary fields collaborating to study those with an acquired disability. Kinesiology and its subdisciplines have much to offer those studying individuals with disabilities.

Conclusion

In his 1981 book, Brooks offers a view of both the field of academic physical education and motor development. Forty years later, it is clear that the field and its subdisciplines have developed into mature areas of scholarship. As we reviewed where we have been over the last four decades and where we see the future grand challenges, we remain optimistic that kinesiology and its subdisciplines have much to offer in addressing the vexing individual as well as sociocultural problems facing us in the 21st century.

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