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In Tribute: Reflections on the Impact of Professor Michael Turvey on Motor Development

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ABBREVIATIONS

ETA Ecological Task Analysis
UCM Uncontrolled Manifold Hypothesis

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ABSTRACT

In our tribute to Professor Michael Turvey, we have two parallel goals: 1) to highlight the scientific scope of Turvey's impact on motor development; and, 2) to expose readers to papers that they may not have read but that might cast new light on age-old questions they confront in their current research on motor development. The paper is divided into two equal time periods. In Part 1, from 1975 to 1999, we trace the emergence and growth of Dynamic Systems/Ecological Realism (perception-action) paradigms. We explain how the existing paradigms in motor development research, the descriptive and information processing paradigms were, in part, replaced by new paradigms whose existence owes much to Michael Turvey and his colleagues. We suggest that this time period was one where Turvey had the most conceptual influence on the field. In Part 2, from 2000 to 2024, we describe how factors, including the emergence of two new paradigms in motor development research may have reduced Turvey's direct influence. But we also note that there is still much research undertaken that builds off the bases of Dynamic Systems and Perception-Action Coupling approaches including research by Turvey and his students/colleagues. We end with the suggestion that the present generation of motor development researchers may have something to gain by re-/reading research from these perspectives regardless of whether it is directly from Professor Turvey's pen or from those whom he influenced (or influenced him).

KEYWORDS: Motor development | Dynamic system | Perception-action | Michael Turvey

INTRODUCTION

In 2006, the first paper in the inaugural issue of the *Brazilian Journal of Motor Behavior* highlighted the history and future directions for motor behavior at the beginning of the 21st century [1]. Not surprisingly, Professor Michael Turvey, was featured as one of the critical thought-leaders in the field. Today, while we are saddened by his passing (August 12, 2023), we are honored to contribute to this special issue of the journal in remembrance of Michael Turvey and his impact on the field of motor development. Motor development we define as, "changes in motor behavior over the lifespan and the process (es) which underlie these changes (p.184)" [2] and it is to understanding the principles that underlie the changes that Professor Turvey had the greatest impact.

As background, we first met and read Professor Turvey in the 1980's. Around this time and later, when asked if he ever considered studying motor development and conducting experiments with children, his answer was an unequivocal "no" - with the rationale that children were too complex to understand! Paradoxically, given his response, Turvey's writings and experiments had, what we consider to be, a profound influence on many motor development researchers and their approach to their scientific experiments and writings.

Our approach in this paper had two parallel goals: 1) to highlight the scientific scope of Turvey's impact on motor development through detailing how motor development researchers referenced and used his work; and, 2) to expose readers to papers that they may not have read but that could cast new light on age-old questions they confront in their current research in motor development. Methodologically, this paper is a subjective, historical, narrative essay that required us to re-read selected Turvey papers and to peruse a range of papers by motor development researchers. The paper is in two parts. In Part 1, we conclude that Professor Turvey's greatest conceptual influence on the study of motor development was circa 1975-1999 and was both direct and indirect. In Part 2, we conclude that his influence still exists, but possibly to a lesser extent. We suggest a potential for a renewed influence in Professor Turvey's and others writings.

PART 1. THE EMERGENCE AND GROWTH OF DYNAMIC SYSTEMS/ECOLOGICAL REALISM PARADIGMS (1975-1999).

We, and others, refer to the chapter in Kelso and Clark's book [3] by Peter Kugler, Scott Kelso & Michael Turvey [4], "On the control and co-ordination of naturally developing systems," as the conceptual beginning of a paradigm shift in motor development [2,5,6]. The Kelso and Clark book was the result of a 1979 conference focused on the development of movement control and coordination with over 20 invited developmentalists (mostly studying movement) discussing their research. While Kugler, Kelso, and Turvey's [4] lengthy, tutorial and challenging chapter, was undoubtedly a seminal work, we would be remiss if we did not raise the following caveats before addressing our mission of highlighting Professor Turvey's contributions to motor development.

First, we recognize, as Kugler, Kelso, and Turvey [4] did, two scientists, Nicolai Bernstein [7] and James Gibson [8] whose ideas were strongly influential respectively to, at that time, the embryonic paradigms of Dynamic Systems and Ecological Realism. We mention this not to suggest that Bernstein and Gibson (among many others referenced) are directly responsible for influencing motor development research. Rather, we emphasize that it was the brilliance of Kugler, Kelso, and Turvey to take the ideas, mostly from other fields such as "philosophy, biology, engineering science and, in particular, non-equilibrium thermodynamics and the ecological approach to perception and action (p.5)" [4] and explicate/apply them to motor development (and motor behavior in general) in a way that ultimately promoted new and heuristic directions of research and increased understanding of existing developmental data.

Second, we recognize that it is not easy to separate the contributions of one person (Professor Turvey) from Professors Kugler and Kelso. We can offer a nod in this direction by looking at publications from Professor Turvey with and without <u>other</u> collaborators. Related to this point is that the Kugler, Kelso, and Turvey [4] chapter was not the first paper to present the principles that eventually led to the paradigmatic changes to Dynamic Systems and Ecological Realism. In addition to the oft-mentioned 1980 paper by the same three authors "On the concept of coordinative structures as dissipative structures", which does not contain a developmental focus but covers some of the same ground [9], there are other far earlier papers. We suggest, Turvey's (1977) [10] paper entitled "Preliminaries to a theory of action with reference to vision" is most notable and, since it was written in 1974 and pre-published in 1975 [11], it anchors our early starting point for his conceptual contributions. Another paper in 1978, this time with Shaw and Mace as co-authors, is entitled "Issues in a theory of action: degrees of freedom, coordinative structures and coalitions" [12]. Taken together, we suggest that Michael Turvey was possibly the prime mover, in bringing the concepts of coordinative structures (functional muscle synergies), a coalition/heterarchical organization (differentiation between the high-level abstract action plan and lower-level autonomous tuning), and a direct matching between visual perception and action (affordances) into prominence. Of course, this is probably a simplification, but it provides a starting point for our historical story of Professor Turvey's influence on motor development research.

As a brief background, in the 1970's motor development research was dominated by two quite separate paradigmatic approaches (e.g.,[2,6]). The first was a descriptive approach chronicling the natural changing behaviors of fundamental motor skills in children (e.g.,[13,14]) or underlying contributing abilities such as strength and cardio-vascular functioning (e.g.,[15,16]). The idea was to map how these naturally occurring motor skills and fitness attributes changed over time and to determine the relationships between the skills and abilities [17]. There was little effort to discover the principles underlying how and why the changes occurred except to refer to neuromuscular maturation and, for some, to recognize an effect of environmental forces like teaching.

The second approach offered an alternative view focused on the underlying factors in the form of information processing abilities such as response selection and programming [18,19] and memory processes [20] using simple laboratory tasks such as reaction time or linear positioning tasks. In this process-oriented perspective, it was hypothesized that central motor programs and schema develop in the brain [21], but again exactly how this might occur was difficult to describe or understand, particularly for complex and whole-body movements. When the Kugler, Kelso, and Turvey [4] chapter was published, a few researchers from both paradigms were ready for conceptualizations that were more explanatory and more grounded in the complexity and dynamics of movement within the environment.

One of the first motor development researchers to refer directly to Turvey's work was Michael Wade in his chapter on the timing (coincident-anticipation) behavior in children published in Kelso & Clark's book [22]. Wade contrasts the conventional information processing framework of either central [21] or peripheral [23] roles of timing in skilled behavior with that of Gibson as expounded by Turvey and his colleagues [12,24,25]. The latter believed that information in the environment directly specifies temporal details of movement that are body-scaled to the mover. While Wade's experiments were not designed to test/support a specific explanation, and his results could be explained by either paradigm; Wade leaned towards the arguments from an ecological realism paradigm writing: "The ecological view, however, argues for a view of timing in which the proper system for analysis is the animal/ environment synergy whereby a compatibility is sought which is sensitive both to the environmental rhythms of timing and to the animal's evolving design which is the complement p. 249)" [22]. Over our Part 1 time-period to 1999 and beyond, Wade remained influenced by the ecological realism approach; for example, in his study on the control of posture in elderly vs younger adults [26]. Here Wade designs the experiment from within the paradigm by comparing changes in optical flow with the maintenance of postural stability and he uses only an ecological interpretation of the results.

While Wade was moving from an information-processing approach towards an ecological (realism) approach, another motor development researcher, who also published in the Kelso & Clark book [3], was one of the book's editors, Jane Clark, who was moving towards what would become known as the Dynamic Systems or sometimes the Bernsteinian Perspective. Like Wade, Clark had been experimentally immersed in the process-oriented approach, in her case studying the complex reaction times of children as they reacted to compatible and incompatible stimuli. She, too, compared the process-oriented explanations of response mechanisms with conceptualizations coming from Turvey [10] and specifically promoting the concept of a coordinative structure. "Such a response-programming system is made possible by having the central executive system make use of the lower level organizations which control individual movement components (p. 164)" [27]. For Clark, the key challenge was how does a coordinative structure arise and how does it evolve? Six years later Clark began to answer this question in a longitudinal study of newborn infant walking [28]. She found that infants appeared to begin walking with a basic coordinative structure in place (defined by interlimb phasing equivalent to adults). How this evolved over the first few months was indicated by a reduction of intralimb coordination variability that was experimentally related to an increase of postural stability. This study spawned a series of papers by Clark & colleagues, all conceptualized within the new Dynamic Systems paradigm [29,30,31,32].

The only other example of direct referencing to Turvey from the chapters of Kelso & Clark [3] was made by Karl Newell [33] in a conceptual chapter on constructing a theory of motor development. References to Turvey emphasize the constancy function of perceiving [10] and the primacy of perceiving for learning [34]. Also, Newell cites both Bernstein [7] and Gibson [35] underscoring an appreciation of the new paradigms, although not yet specifically using their work to devise experiments or explain existing data. Newell [36], however, went on to write a very accessible and influential conceptual paper expanding the concept of constraints and action by illustrating the existence of three different types: organismic, task and environment, and their potential roles when interacting through development (and learning). This conceptualization became known as the "constraints model" and has been used as a theoretical framework by many followers. Thus Newell, while directly influenced by Turvey, became, himself, an influencer for those in motor development providing, what we will call, an indirect effect of the Turvey influence. Newell also began to devise classic experiments influenced by both dynamic systems and ecological realism concepts (especially affordances) exploring the relationship between hand grips used by children and adults [37] and by infants from four to eight months [38] relative to hand-size and the size of the object to be grasped. In these experiments, when the object is scaled to hand size there is a commonality in the limited number of grasp patterns afforded illustrating the concept that constraints limit rather than prescribe, what is possible. The implications for motor assessment are profound.

Thus far we have mentioned only three early adopters of concepts from Kugler, Kelso, and Turvey [4] and Turvey papers out of 12 chapters in the Kelso and Clark conference book (25%). We now consider another conference that invited leading motor development specialists this time from all over the world. Supported by NATO as part of its Advanced Science Institutes series on Behavioural and Social Science, Whiting and Wade invited 45 speakers and produced two edited books both published in 1986 [39,40]. At this conference, sixteen researchers (36%; including Clark, Newell and Wade) referred to Turvey's work with four of the 16 mentioning him collectively as part of Kugler, Kelso, and Turvey papers [4,9] while the others cited many of his other papers as well. Of the thirteen researchers not already mentioned we will highlight two researchers and list the remaining 11 here alphabetically: P.J. Beek, B. Bril, J.C. Fentress, B. Hopkins, M. Jeannerod, P.N. Kugler, G. Reid, M.A. Roberton, P.C.W. van Wieringen, P.H. Wolff, and, H. Zelaznik.

The first paper we highlight was by Walter Davis [41], an adapted physical educator, interested in understanding motor deficiencies in children who were mentally handicapped. He began his paper stating the lack of a viable theoretical framework and rejecting the information processing approach. He then offered the following: "One theoretical approach offering insight … views coordination and control as arising from a mutually constrained actor-environment system (Fowler & Turvey, 1978)(p. 144)" [41]. Davis goes on to cite empirical evidence of a coordinative structure of muscles functioning as a mass-spring system that operates similarly in both the typically developing and mentally handicapped individuals but differs in how the unit is parameterized, that is, how it is controlled [42]. In addition to Davis's empirical work, we want to particularly emphasize a well-cited article entitled "Ecological Task Analysis: Translating Movement Behavior Theory into Practice" that he published with Alan Burton [43]. Leaning heavily on Kugler, Kelso, Turvey [4] as well as three other Turvey articles and Gibson, Davis & Burton update the traditional developmental task analyses of Herkowitz [44] and Morris [45] by, among many other changes, considering the concept of body-scaled affordances.

A second noteworthy contributor to the conference was Esther Thelen, a developmental ethologist by training, who had become one of the most well-known motor development researchers by the early 1980's. She began her career by making naturalistic longitudinal observations of rhythmic stereotypies in normal human infants. Since the onset of particular stereotypies were highly correlated with motor development, Thelen proposed that they were "manifestations of incomplete cortical control of endogenous patterning in maturing neuromuscular pathways (p. 699)" [46]. In 1980, she proposed that a deficiency of vestibular stimulation may be one determinant of persistent stereotypy [47]. And the next year, she suggested that "rhythmic stereotypies are a development of intrinsic central motor programs (p. 237)" [48]. At this time, from her cited references, it appears that Thelen was following a biological maturation based central pattern generator explanation. It is not until 1984 that we see clear referencing to Kugler, Kelso and Turvey's papers [4,9] and the importance of dynamic qualities in development. "Movement, they argue, is as much a product of the mass stiffness, and inertial properties of the limbs as of central neural properties (p.479)" [49]. Based on their data from three studies, Thelen and her colleagues challenged the traditional explanation for the disappearance of the "primitive" stepping reflex being the suppression by maturation of inhibitory tracts from the cortex. Instead, they demonstrate that a probable cause is simple physical growth that causes a temporary loss of strength which can be ameliorated with training and does not require either maturation or cognitive change for explanation [50,51].

While Thelen began to interpret her past work within a dynamical approach she, like Newell, also wrote solo conceptual papers [52,53,54]. In 1986, Thelen described a systems strategy to determine how an early generalized coordinative structure (for walking) would change over time depending on "outcomes of interacting components, each with its own developmental course and acting within definitive constraints and opportunities afforded by the context (p.110)" [54]. This paper and others, written with authors, Scott Kelso and Alan Fogel [55] entitled, "Self-organizing systems and infant motor development," and Beverley Ulrich [56] entitled, "Hidden skills: A dynamic systems analysis of treadmill stepping during the first year," were well-cited and our point, as with Newell [36], is to suggest that reference to any of these conceptual papers are an indirect way of recognizing the influence of Turvey since he is acknowledged as influential by the writers themselves. Of course, this may not mean that someone reading and following Newell or Thelen will actually realize/acknowledge that Turvey is indirectly one of their own influencers. Nevertheless, an indirect influence is still valid for our purpose. In addition, references to conceptual papers of Scott Kelso and Peter Kugler up to about 1990 also come into this category of indirect influence when Turvey is not a co-author.

In 1990, there was third conference on motor development again funded by NATO. Bloch & Bertenthal [57], the conference organizers, invited 34 contributors to the conference entitled "Sensory-Motor Organizations and Development in Infancy and Early Childhood." For this conference 13 scientists in attendance either directly cited Turvey (8) or cited others influenced by Turvey (5). This number equals 38%, similar to the previous conference, but, it should be noted, there were more people present who were psychologists rather than those who were singularly focused on motor development. Unlike the previous conference, five papers mentioned the dynamic systems/approach and or perception-action coupling in their titles. With Newell, Clark and Thelen present, we will highlight just one individual. The remaining nine citing Turvey directly or indirectly are listed here (alphabetically): J. Benson, B.I. Bertenthal, H. Bloch, G. Butterworth, A. Fogel, Y. Hatwell, A.F. Petersen, W. Warren, and M.H. Woollacott.

Our choice to highlight from the 1990 conference is Eugene Goldfield, a developmental psychologist, who, while tasked with discussing two other papers, chose also to "discuss three issues about perceptual-motor development from a dynamical systems perspective: (1) the brain-behavior relation, (2) flexibility and stability of behavior, and (3) emergent functions (p. 187)" [58]. This short and accessible chapter remains a good read for those who find the Kugler, Kelso, and Turvey [4] paper less accessible, although we absolutely recommend reading the latter. Goldfield's work is notable, not only for a continued "use" of the dynamic systems perspective in terms of concepts (such as coordination; tuning) and methods (such as relative phase and stability), but in the practical research questions that addressed topics such as learning to use an infant bouncer [59] and coordination of sucking and swallowing during breast and bottle feeding [60].

To our knowledge there are no recent nor invited conference books on motor development where we might continue to look for evidence of the influence of Professor Turvey and the use of a dynamic systems perspective and/or ecological realism (i.e., perception-action coupling as we shall call it going forward in line with common usage). We recognize that there are many more motor development researchers that we could mention, often students or colleagues of those already mentioned. As we conclude this first era, we provide a selected exemplar list of motor development scientists, in addition to those already discussed or mentioned, who are representative of the empirical work influenced by the new paradigms (listed alphabetically): K. Adolph[61,62], D. Corbetta [63], J. Jensen [64], J. Konczak [65], E. Reed [66,67], G. Savelsbergh [68], B. Ulrich [69], J. Whitall [70].

Finally, we wish to recognize that Turvey [71] wrote a commentary in a special issue of the journal, *Child Development* entitled, "Developmental Biodynamics: Brain, Body and Behavior Connections". In their paper, Turvey and Fitzpatrick discuss the development and function of perception-action systems (i.e., motor skills identifiable by collective variables and changed by control parameters) as pattern formation processes or, more generally, as dynamical systems. This article has practical empirical suggestions and drew many citations including those studying basic developmental mechanisms [72], the role of variability in early motor development [73] and clapping [74].

To summarize Part 1, (1975-1999), we have shown that the influence of Professor Turvey and his colleagues on motor development researchers grew substantively during the last twenty-five years of the 20th century. Many began to use either a dynamic systems or a perception-action (or both) perspective to understanding the development of motor skills. While we only highlighted six researchers (and mentioned over 30 others) there were clearly many more. The examples chosen and indeed almost all of the studies we are aware of during this period are focused on infancy and childhood. To be clear, not all researchers in motor development used these frameworks and even some who did were not always referring directly to Professor Turvey's work. However, all of the major textbooks on motor development by 2000 and continued to the present had sections discussing the Dynamical Systems and Perception-Action paradigms with reference to Professor Turvey (Current editions of these texts include [75,76,77,78,79]). Even Connolly and Forssberg's [80] edited book, neither of whom were known for following these paradigms have chapters with authors who referenced Turvey's work [81,82].

We close Part 1 as we start the year 2000 because, in our history of motor development research [6,83], we have marked this time point as approximately when the Dynamical Systems and, to a lesser extent, the Perception-Action Approach began to yield to other approaches to motor development research. This transition is quantitatively illustrated in Clark's illustration of decades of motor development research using Wordles [84] (see Figs. 4, 5 & 6).

PART 2: MOTOR DEVELOPMENT AT THE START OF THE 21ST CENTURY (2000-2024)

In 1990, the US National Institutes of Health declared the 90s the "Decade of the Brain" [85]. Obviously, the impact on behavioral science and motor development included, was to shift the emphasis to studying the brain without necessarily incorporating action. In combination with a variety of new neuroscience methodologies, some motor development researchers began adding brain measures to their studies but without typically bringing with them a rigorous analysis of brain dynamics in conjunction with behavioral dynamics that might be part of a dynamic systems approach [86]. We have broadly named this type of research a "Developmental Motor Neuroscience" approach [83]. As we view it, researchers from this perspective are interested in brain-behavior interactions and/or in modeling motor control from a neuroanatomical or engineering perspective. Explanations of cognition-movement interaction seem, at least on the surface, to be driven more by prescription than by self-organization and a constraints perspective that would be more consistent with a Dynamic Systems/Perception-Action approach.

Another paradigm that has emerged in the 21st century, we named a "Developmental Health" approach [83]. Again, an important force for this research came from the US National Institutes of Health and the Office of the Surgeon General that both called for action to address the growing prevalence of overweight and obesity in the population (Office of the Surgeon General [US] and National Institutes of Health [US], 2001 [87]). Many researchers began to focus on the use and promotion of motor skill development and physical activity and especially how children became unfit and overweight. Many adopted a conceptual model[88] that tied together concepts such as self-efficacy, fitness, motor competence and motor activity. This approach used correlational analyses as a principal analytical tool, with little interest in situating the work in a broader Dynamical Systems or Perception Action framework.

Clearly, both the impact of society to address the obesity epidemic and the importance of understanding cognitive motor neuroscience were important forces in reducing the amount of research conducted specifically within a dynamical systems or perception-action paradigm. But we should not overlook another potential factor, the untimely deaths of two important and influential researchers. Esther Thelen died in 2004 at 63 years. To say that she, herself, was also an influencer is an understatement and it is impossible to know how many contributions she would have made or researchers influenced if she had lived even five more years. As Turvey, himself, opined at her memorial service, "she moved her science (p. 106)" [89].

The other untimely death was that of Alan Burton in 2001 at the young age of 47 years. We believe his work with Walter Davis on an "Ecological Task Analysis" (ETA) [43] would have had a larger effect on motor development researchers, particularly those interested in assessing motor abilities. To be fair, Davis did promote the ETA as seen in his edited book with Broadhead [90]. In our opinion, more credit and use of the ETA would seem warranted.

While the Motor Neuroscience and Health dominant approaches may represent much of the research in motor development in the first quarter of the 21st century, the influence of Turvey and his work is still very evident. First, for example in 2006, Turvey was invited as the keynote speaker for the motor development section at the North American Society for the Study of Sport and Physical Activity. Second, as we noted in Whitall et al. [83], there is still a cadre of motor development researchers who have continued following and expanding concepts from Dynamical Systems and Perception-Action paradigms [83]. As Thelen argued in 2000, motor development is critical to understanding development as a whole, because all systems interact to produce behavioral development [91]. Therefore, systems such as the motor, cognition, perception, and linguistics need to be considered together more formally than in the past and might best be labeled under a "unifying" theoretical perspective named Developmental Systems [92]. We, and others, have embraced this name to describe a perspective of interacting developing systems with a central but not always primary role for motor systems [83,93]. Our argument for the purposes of this paper is that this approach is a natural legacy of the Dynamical Systems and Perception-Action paradigms. This could be considered a mixture of direct and indirect influence of Turvey because references to intermediaries such as Thelen abound as well as to Bernstein and Gibson whom Turvey and others brought to everyone's attention back in the late 1970s.

A second continuing indirect influence of Turvey is the widespread reference to Newell's constraints model as a "conceptual" framework. Researchers from both the Developmental Health and Developmental Motor Neuroscience perspectives seem to incorporate the constraints model in this way as revealed by a cursory look at the first authors of the first 100 citations (out of over 3,311 in Google Scholar, February 9, 2024) of Newell's 1986 article [36]. Third, although we have already stated that the Developmental Health and Developmental Motor Neuroscience perspectives are most prominent certainly within the Kinesiological field of researchers, there are several "pockets" of researchers who are continuing to use an overall Dynamical Systems and/or Perception-Action perspective but have built on this foundation in different ways. We will mention four briefly, and note that the "originators/leaders" of these pockets are not, strictly speaking, motor development researchers, but do, sometimes, work on developmental questions with others.

One pocket of researchers comes from those interested in the role of variability in movement behavior. Gregor Schöner proposed the uncontrolled manifold hypothesis (UCM) and elaborated on it with John Scholz [94] and Mark Latash [95]. The hypothesis demonstrates how variability can be good (allowing flexibility) when it does not affect the task goal; or bad (affecting performance) when it does. Developmentally, we can ask when and how good variability overtakes bad variability to produce more optimal control of a movement. Several studies have used the UCM analysis to compare typically developing children with clinical populations, but few have studied motor development either longitudinally or cross-sectionally. One exception is Golenia and colleagues [96] who investigated children's reaching using UCM and cites Turvey & Fitzpatrick [71] among many other dynamical systems scientists.

A second pocket of research also centers on the role and analysis of variability in movement behavior. Nick Stergiou began his career using a dynamical systems approach to study leg coordination in running [97]. He then promoted non-linear dynamic methods of analyzing variability in part to include the temporal structure of variability that is lost when using linear methods that simply characterize the overall amount of variability [98]. He and others have used non-linear (and linear) analysis to assess postural control in young infants at different stages of development [99] and to assess aging effects on variability during gait [100]. More recently, Stergiou has been studying self-motion during overground locomotion in adults and references many Turvey articles [101].

A third pocket of research built on a Dynamical Systems/Perception-action perspective centers on the work of Keith Davids and colleagues. In contrast to the afore-mentioned uncontrolled manifold and non-linear dynamic analyses of movement variability approaches, often utilized to answer motor control or clinical questions, the ecological dynamics approach to skill acquisition [102] is oriented toward education and sport contexts. This approach is an integration of Ecological Psychology, Dynamical Systems, Evolutionary Science and the Science of Complex Systems. It is clear from the references of Davids two well-cited books on *Visual Perception and Action in Sport* [103] and *Dynamics of Skill Acquisition: A Constraints-led Approach* [104] that Turvey and colleagues have been major influences on this work.

As a fourth pocket, Karl Newell and his students/colleagues have also continued to build on the Dynamical Systems/Perception-Action approach both theoretically and empirically. For example, a theoretical paper on time scales in motor learning and development [105] was based on the concepts and tools of non-linear dynamical systems and provided a principled explanation for both short-term transitory learning and long-term developmental changes. This paper was followed by one that re-interpreted the traditional landscape metaphor for infant motor development into a more formal model of a dynamical system that considers multiple time scales [106]. To our knowledge, the excellent suggestions made for future infant research have not been pursued. Another line of work challenged the information processing account that the amount of white gaussian noise in the perceptual-motor system of children's motor behaviors decreased with age and was associated with improved accuracy and variability [107]. Using non-linear methods to assess the structure of variability citing Riley and Turvey's work [108] and over a number of experiments Deutsch & Newell found evidence of a strong link between performance and the deterministic structure of variability that was relatively independent of age and did not support the information processing hypothesis. Unlike the other three pockets we have presented, Newell, has a record of contributing to motor development research including work on aging. We will mention one last paper that is more in line with Professor David's approach. In 2021, Newell and Rovegno [109] published an article on teaching children motor skills for team games through guided discovery - using a constraints approach. For anyone interested in advancing and understanding the development of children's movement skills in physical activity, this is well worth a read. The influence of Michael Turvey is a clear presence (i.e., five Turvey citations).

We mention the above four pockets of indirect influence to encourage current motor development researchers to investigate whether any of these pockets might offer new insights or new methods for answering their own research questions. For example, the variety of non-linear methods for assessing variability (found within each pocket) may be useful to those operating within a Developmental Motor Neuroscience arena. For those operating within a Developmental Health arena the work from Davids and Newell may be useful. Finally, there is one more source of direct influence to briefly discuss and that is from Turvey's own writing after his second conceptual paper on development with Fitzpatrick [71] mentioned at the end of Part 1. To our knowledge, Turvey, did not write any further conceptual papers on development; nor did he conduct experiments with children. On the other hand, Turvey's students conducted several experiments on what we might call fundamental motor skills, although usually in adults or with theoretical models. For example, Peck & Turvey [110] investigated the coordination dynamics of galloping using the bilateral pendulum model in adults [111] and comparing to children's results [112,113]. Lopresti-Goodman and colleagues [114] investigated transitions between different modes of grasping (one or two handed) looking at body-scaled affordance perception within a dynamical system. In another study, Kinsella-Shaw and colleagues [115] investigated interleg coordination in quiet standing in young and older adults and the effect of age and visual environment on noise and stability. Perhaps even more relevant for those motor developers interested in developing sport skills is a paper by Fajen [116] that discussed how information and the theory of affordances both have the potential to become guiding principles of perception and action in sport. The authors conclusion at the time was that information was being tested more than affordances and they provide examples for the latter.

Finally, there are two reflective papers we think are worth reading because they have a clarity of hindsight as well as thoughts for the future. In 2012, Turvey [11] responded to some questions posed to him in a paper entitled "From Physical Education to Physical Intelligence: 50 years of Perception-Action by Michael T. Turvey". He describes both the origin of his interest in perception and action circa 1962 and how his thinking has been influenced over time. Curiously, he makes the argument that not much has changed in ecological psychology since 1988 and then makes an impassioned plea that "Physics is not done yet … Only by recognizing and addressing the incompleteness of physics can we hope to reverse the historical tendency of treating perceiving, acting, and knowing as necessitating special explanation outside the purview of universal physical principles (p. 135-136)" [11]. In 2013, Turvey [117] expands these remarks in "Ecological Perspective on Perception-Action: What kind of Science does it entail". This chapter highlights principles of Ecological Psychology in general (it applies to all phyla) and to affordances, in particular. Both papers are worth reading. We recognize that there are many other recent papers that might attract other motor development researchers and encourage attention to these.

To summarize, in Part 2 (2000-2024) we have presented arguments both for and against the proposition that the influence of Professor Turvey may be less prevalent than during Part 1. Certainly that may be true for those in the field of motor development operating within a Motor Neuroscience or Health perspective. We have also offered arguments that suggest his influence is still present even if some of this is indirect. From the large corpus and impact of Professor Michael Turvey's work, it is impossible to do him justice in one article. We also limited our scope by not including many developmental researchers from medical fields such as physical therapy and we surely omitted many whose work was influenced by Turvey – for this we apologize. To return to our goals from the beginning: we hope we have adequately reflected on and honored Michael Turvey's legacy to the field of motor development; and also inspired those currently in the field of motor development to revisit the work and legacy of Michael Turvey either directly or indirectly. As a field, our developmental trajectory and our developmental landscape have been shaped by this great scholar. Thank you, Michael Turvey.

POSTSCRIPT

The last time we met Mike was in 2012 at the International Feldenkrais Conference where each of us were invited to speak at the Esther Thelen Research Symposium. It feels like only yesterday that the four of us (with Claudia) repaired to the bar that evening to chat over a beer or two. We had no idea this would be the last time we would see him. Suffice to say, we have enjoyed immensely our, albeit infrequent, conversations over the years. Jill and Mike shared an avid affection for Arsenal Football Club and she, especially, appreciated the "shrine" in Mike's at-home pub. Again, we are honored to write about his large and continuing influence on motor development research. Michael Turvey certainly influenced us.

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