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Beyond Motor Development: Methodological Implications of Dynamic Systems and Applications to Social Domains

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Developmental scientists have increasingly used systems approaches to understand complex, multi-dimensional changes that occur over the life span. Dynamics system theory (Kelso, 1995; Thelen & Smith, 2006) has been especially popular for studying motor development, and it is this approach that undergirds the work described by Brakke and Pacheco (2019) in their monograph, *The Development of Bimanual Coordination Across Toddlerhood.* Their work involves measuring behavior continuously, and then using time-series analytic techniques to reveal the dynamic structure of that behavior. These techniques reveal developmental changes in patterning and strength of system-components. The data provided by examining moment-to-moment and ontogenetic change reveal subtle dimensions of coordination that are typically missed when only gross measures of skill outcomes are used.

In my comments I first highlight several important features of dynamic systems methodology used by Brakke and Pacheco which have implications for future developmental research. I then illustrate the more general utility of this methodology by discussing how it has been used to study social development in both typically-developing and clinical populations.

Brakke and Pacheco employed a dynamic system approach using a coupled oscillator model to evaluate the developmental progression of bimanual drumming behavior in toddlers. They tested toddlers monthly, and evaluated how factors of frequency of oscillation, amplitude, and initial condition influenced toddlers' behavior both within trials and across the months of the experiment. They found that initially, toddlers were able to perform bimanual drumming; however, toddlers' performance was not stable and very few cycles could be performed in

sequence. Developmentally, anti-phase performance became more stable and increasing numbers of drumming cycles were performed in sequence. Improvement in performance was related to modulation of frequency and amplitude both within and across trials, and initial conditions influenced the unfolding of behavior over the course of a trial.

Brakke and Pacheco's research is worthwhile because very little previous work has been done to understand the emergence of bimanual coordination in toddlers. Thus, this work fills an important gap. However, an even greater contribution of their work lies in its methodological implications for future research. First, their use of a well-tested formal model provides a robust model for capturing and understanding the process of behavior-change over time. It is worth emphasizing that this type of modeling allows the examination of the *process* of change in general and is not tied to a specific type of behavior. Thus, dynamical modelling is not limited to motor coordination but can be applied to a broad range of developmental domains. It is also worth noting that many aspects of psychological functioning (e.g., perceptions, thoughts, emotions) are embodied and provide observable behavior which offers a very rich window to study internal processes that are of interest to developmental scientists.

In addition, Brakke and Pacheco employed a longitudinal design, which allowed an evaluation of changes in behavior at the level of the individual as well as the group. They found that only half the toddlers demonstrated the developmental pathway they proposed—confirming that the developmental timelines and trajectories for children are varied. This, of course, is not surprising. However, it does demonstrate that grouping participants based on chronological age can obscure important information about developmental processes. Choosing an endpoint based on competency might be a better grouping strategy than age. The question then becomes one of analyzing the patterns of change that drive development to that endpoint. Importantly, because there are many variables to be modified and many pathways to a solution, it is not necessary for all participants to demonstrate the same pattern. The presence of such variations is the inspiration for looking at individual participants' data. Doing so provides an opportunity to identify varied patterns, and then to use a higher level of analysis to explore commonalities across them. Such an approach is possible only by collecting a fine-grained, robust dataset such as the one collected by Brakke and Pacheco.

Brakke and Pacheco's monograph also presents developmental scientists with an opportunity to re-examine common experimental procedures and consider whether they are optimal for analyzing change over multiple time scales. For example, some readers of the monograph may have had concerns about the variations in experimental methods, as, for example, variations in the length of individual trials or in the number of months of data used for modeling. While such variations are problematic in some ways, the benefits of less-constrained methodologies mitigate some of the concerns. Very dense microgenetic analyses of longitudinal data offer richness that is often missing in cross-sectional research. In addition, given that developmental processes are inherently variable, inconsistent, and messy, it is helpful to embrace that complexity rather than try to control it. For example, allowing children to approach tasks in their own ways, examining data with respect to skill-level rather than age, and ending experiments at a pre-specified target outcome rather than at a pre-specified age are all likely to be instrumental for moving developmental science forward. Brakke and Pacheco also took the unusual strategy of providing an in-depth discussion of the parameters that did *not* change. Characterizing both the parameters that are changing as well as the ones that are not changing is important. Thus, this work is worthwhile because it challenges some long-held traditions about experimental design, rigor, and reporting of data.

Furthermore, toddlers are an understudied age group in developmental science. Brakke and Pacheco should be commended for choosing this age group given that their overarching objective was to capture the emergence of behavior during early learning. While skilled behavior was not achieved by all toddlers by the end of data collection, analyzing this phase of skill development did reveal the instability of behavior during early learning. The field would benefit from future research that explores the processes involved in stabilizing bimanual coordination.

The dynamic systems approach has also been instrumental in advancing understanding of social interactions and has demonstrated that the strength of interpersonal synchronization is affected by many different physical as well as psychological variables (see Schmidt & Fitzpatrick, 2016 for a history). During social interactions, the body movements of two people have a tendency to become synchronized such that the timing of their movements is simultaneous or complementary. This phenomenon of social synchrony can occur both intentionally (for

example, when two people perform an activity together to accomplish an explicit social goal) as well as spontaneously (outside conscious awareness, for example, when the body sway of two people becomes synchronized during a conversation). The same coupled-oscillator dynamic that Brakke and Pacheco used to study the emergence of interlimb coordination in toddlers has also been applied to study social coordination.

More recently, the dynamic systems approach has been used in both laboratory and naturalistic tasks to compare synchronization patterns of typically developing children and children from clinical populations characterized by social difficulties, such as autism spectrum disorder (ASD). For example, Fitzpatrick et al. (2017b, 2018) found that both school-age children and adolescents with ASD demonstrated lower social synchronization abilities. Romero et al. (2018) also used the dynamic systems approach to analyze synchrony of whole-body movements during conversation. They found that children with ASD coordinated their bodily movements with a partner during conversation, and the degree of synchronization was related to higher social ability. Taken together, this research suggests that objective measures and dynamical modeling of social synchronization provide insights into understanding social behavior generally, and also have important implications for better characterizing ASD traits, in particular.

In summary, Brakke and Pacheco's monograph contributes to developmental science in three important ways. First, their research has expanded understanding of the developmental change patterns linked to emerging skills of bimanual coordination. Second, and perhaps more importantly, their research highlights the value of applying dynamical, microgenetic, and longitudinal approaches to study patterns of developmental change at both individual and group levels. Finally, their work reminds developmental scientists that methodologies that originated in the study of motor development may be fruitfully applied in other developmental domains, an application illustrated by the research my colleagues and I have done which examines the development of social synchrony in children with and without ASD.

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