

Lockman, J. J. (2019). *Embracing process: Developmental change in action*. [Peer commentary on the article "[The development of bimanual coordination across toddlerhood](#)" by K. Brakke and M. M. Pacheco]. *Monograph Matters*. Retrieved from <https://monographmatters.srkd.org/2019/05/30/commentary-lockman-84-2/>

Embracing Process: Developmental Change in Action

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How do earlier forms of abilities give rise to new ones? This is a central question of developmental science, and one that underlies much of the work that is reported by [Brakke and Pacheco \(2019\)](#) in their inspiring monograph, *The Development of Bimanual Coordination Across Toddlerhood*. This monograph is of course about motor development, but it is also about something more. It addresses fundamental issues about where new competencies come from and how they build on old ones. Here, bimanual coordination serves as a model system to understand developmental change. The monograph documents how a focus on process in real time can illuminate change over developmental time. The work holds lessons for understanding not only motor development, but other domains of development as well.

With reference to motor development, this work fills a curious gap. The adult motor control literature is replete with studies on bimanual synchronization, typically measured with some type of finger tapping task. At first blush, finger tapping might seem like a niche skill to examine, not to mention of questionable ecological validity. Yet, it turns out that finger tapping provides in many ways an ideal entry point to access the oscillatory dynamics of the manual system. Bimanual finger tapping affords insight into (a) which patterns of synchronization are privileged (e.g., the in-phase and anti-phase patterns investigated in the monograph), (b) which spatiotemporal parameters shift the system from one pattern of synchronization to another, and (c) which parameters govern stability, once synchronization is attained. Moreover, this dynamical approach, in part derived from work on physical systems, can be formally modeled (as was done with the Haken-Kelso-Bunz model used in the current monograph), leading to specification of parameters associated with behavioral stability and change. The dynamical approach has also served as an entry point from which to consider development more broadly. In their pioneering work on dynamic systems and development, Thelen and Smith (1994) adapted many of these constructs to consider the mechanisms and processes of microgenetic and ontogenetic change, and how change across these two time scales is related.

Despite the fact that much of the original behavioral work with adults on dynamic systems theory was grounded in research on bimanual coordination, developmental researchers who initially adopted this approach focused mainly on locomotion (e.g., see Thelen & Ulrich, 1991)

and to a lesser extent, unimanual reaching (Thelen et al., 1993). Developmental research on bimanual coordination as originally conceptualized in much of the adult motor control literature on dynamic systems theory was rare (for an exception, see work on the development of clapping, Fitzpatrick, Schmidt, & Lockman, 1996). Why was this the case? Developmental researchers may have been concerned about the face validity of finger tapping as a behavior warranting study. The monograph by Brakke and Pacheco, however, brings us full circle. The work reported here uses an oscillatory and, I might add, a delightful toddler task--drumming. It uses the full power of the original dynamic systems approach to explore how young children begin to control the intrinsic dynamics of their arms. It adopts a multi-method strategy, integrating quantitative and qualitative methods as well as group and individual analyses, to understand how toddlers attempt coordination. And by doing so, the work invites us to consider how change is achieved both microgenetically and ontogenetically. Process is key.

A related benefit of focusing on process is that it imparts a finer lens on outcome. Children may arrive at the same outcome by controlling or weighting the same or different parameters in different ways, illustrating the developmental phenomenon of equifinality of outcome (Cicchetti & Rogosch, 1996; Mayr, 1988). In the field of motor development, Esther Thelen documented this phenomenon in her studies on reaching. Thelen and colleagues showed that infants learn to control the unique dynamics of their bodies as they work out the problem of extending their hand to a visually perceived target (Thelen et al., 1993). Similarly, in the present monograph, Brakke and Pacheco show us that on an individual level, toddlers may control different movement parameters to achieve in-phase and anti-phase patterns of bimanual coordination.

Focusing on process confers many advantages. Just as important, ignoring process incurs costs. By considering only outcome, researchers might overlook developmental changes or individual differences in process, particularly when there is little variation in outcome. Consider, for instance, the use of developmental checklists in the motor domain. Many of these checklists require parents or an observer to make a binary (yes/no) or ternary (yes/sometimes or partial/no) response regarding the presence or absence of a skill. However, as the research reported in this monograph suggests, even though children may be able to partially or fully perform a skill, the process by which they do so may vary. Such variation could inform interpretation of measures scored on a yes/no basis.

Consider also findings from the literature on school readiness. Investigators have documented linkages between preschool performance on fine motor tasks (each typically assessed using a 0/1 or a 0/1/2 scale), and kindergarten achievement and first-grade math ability. Yet the reasons for these associations are not clear (Cameron, Cottone, Murrah, & Grissmer, 2016). Information about process, however, might illuminate why preschool fine motor skills and early academic performance are developmentally related or what aspects of prior fine motor performance set the stage for subsequent success in the early school years. In a similar vein, in

the pediatric physical therapy field, reliance on motor checklists to the exclusion of information about process may obscure child strengths as well as potential avenues for intervention (Heathcock & Lockman, in press).

Or consider an example from our work on planning and object fitting with motion tracking technology (Jung, Kahrs, & Lockman, 2015, 2018). Motion tracking technology enables us to glimpse the moment-by-moment spatial adjustments that children make as they transport an object to insert it into a matching aperture. A focus on process indicates that between two and three years of age, children become more efficient in how they achieve fitting. By two years, children first translate the object (i.e., move it laterally) to the aperture, and then systematically rotate the object to match the aperture's orientation. In contrast, by three years, children make these spatial adjustments simultaneously. A focus on outcome alone (i.e., fitting) would have missed these advances in planning.

The present monograph rightfully turns our attention to process--in this case, how young children begin to couple the simultaneous oscillations of the two arms. Studying the process by which children attempt this type of bimanual coordination in real time provides a close-up view of how children begin to effect change over developmental time. As this monograph so beautifully shows, children fall in and out of coordination and adjust different movement parameters to bring about more stable forms of bimanual synchronization across different time scales.

With an innovative effort such as this, there are inevitably some loose ends. For example, and as the authors note, the location of children's grips on the drumsticks was not constrained. Failure to constrain grip location, however, may have introduced individual and age-related variation in the amplitude parameters that children needed to adjust to achieve bimanual coordination. Additionally, kinematic data were analyzed in two rather than three dimensions, so it is possible that the overall distance that the drumsticks traveled in three-dimensional space might be another parameter that toddlers needed to control to achieve coordination. Finally, and again as noted by the authors, metronome rate varied in the in-phase and anti-phase modeling conditions, complicating direct comparisons across the two conditions. But these issues do not detract from the authors' overall achievement. My hope is that this work will inspire other like-minded empirical efforts, not just in motor development, but in other domains as well. By embracing process directly in our studies, we advance developmental science.

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