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Short Communication

Hybrid is not a dirty word: Commentary on Wade and Kazeck (2017)

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The review by Wade presents some provocative arguments on the state of research and hypotheses on the possible cause(s) of developmental coordination disorder (DCD). He contends that degrading of perception-action coupling (i.e., dynamical systems approach) better explains the motor deficits seen in children with DCD than problems in internal modelling (i.e., information processing approach). However, Wade's assessment lacks an appreciation of how experimental work on DCD has progressed over the past 10–15 years, moving beyond the narrow box-and-arrow models of traditional information processing (IP) theory and into the realm of cognitive neuroscience. Indeed, Wade's critique overlooks a large body of recent work that would help dispel many of the misgivings that he presents in his paper. The following commentary will highlight what we consider are the main points in defence of the cognitive neuroscientific investigation of DCD. We will also discuss areas of weakness in present theoretical models and how ecological principles gleaned from a dynamical systems approach could inform and enrich our understanding of the underlying cause(s) of DCD going forward.

1. A mid-century straw man (or Mr. Schema does not live here anymore)

The recent body of experimental work on DCD has largely moved beyond the narrow confines of traditional IP theory. Wade presents, however, a straw man stuffed with concepts that few today would consider valid representations of the motor system: *motor schema*, *motor program*, “sense-think-act cycle”, etc. are presented as being synonymous with current thinking. In actual fact, constructs like *motor program* for example have not been a focus of DCD research for 20 years or more. Such constructs carry with them a lot of conceptual baggage, including the idea that processing occurs in a linear fashion from input to output. Few present-day researchers would subscribe to this view, and yet Wade argues that thinking in the DCD field is still constrained by it. This position is supported by a selective and limited critique of the actual work that has been conducted on DCD, over the last decade. Since our 2012 *meta-analysis* (Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013) there have been well over 100 experimental studies on DCD, and nearly 20 neuroimaging studies, alone. Wade's review cites 5 individual studies conducted after 2009 (two his own), and only one study published after 2012 (an excellent paper by Wilmut, Du, and Barnett (2015)). This is not an informed platform on which to base this stinging critique.

Without doubt, the field of cognitive neuroscience (and its various offshoots) presents a stark contrast with traditional IP theory. Not only has the discourse moved to understanding brain-behaviour relations but also to how the brain is modified in a reciprocal manner by the environment and experience, whether over short timescales or longer (e.g., Koziol & et al., 2014),

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and how an individual's genetic makeup can influence brains and behaviour (Mosca & et al., 2016). This more refined version of cognitive neuroscience also implies a synergistic relationship between the individual performer and the environment, even if the methods are generally focused on a tightly controlled set of parameters (*viz* task constraints). Moreover, notions of modularity in the structure of the brain have given way to interactive network models (e.g., Sripada, Kessler, & Angstadt, 2016) and developmental theories like *interactive specialisation* (Johnson, 2011). These theoretical advances have in fact broadened the view of cognition and action as an embodied phenomenon. On the importance of this development in knowledge and understanding, we agree with Wade. Unlike Wade, we do not draw a distinction between notions of embodied cognition and general trends in the experimental investigation of DCD over recent years.

The notion of *embodied cognition* (EC) is not specific to traditional ecological theory (despite what is implied by Wade), but rather is an important notion in modern conceptions of thought and action from a broad cognitive science perspective. The very notion of EC acknowledges the centrality of the physical system in development and learning, even with respect to how higher-order knowledge constructs are developed through experience (Gallesse & Lakoff, 2005). In the case of motor behaviour, the quest to model these basic biological systems in action is not an act of surrender to reductionist logic. We would agree that by the deft hand of evolution, action systems are exquisitely attuned to information from the ambient environment (and not “meaningless inputs” to quote Wade); these basic systems bias processing in ways that serve action goals and survival. We are intimately intrigued by this notion, and seek to identify and understand the structure (and function) of these basic neuromotor systems, how they change with maturation, and at the same time are shaped by the environment. Whether called mechanistic or not, this quest is important to fully understand typical motor development, developmental delays, and significant departures from typical growth patterns (Ruddock et al., 2016).

We concede that the part of the equation that has remained elusive in studies of DCD concerns the dynamic interplay between movement, experience and developing brain systems. We are starting to see some inroads into this dynamic in other fields that study structural neuroplasticity in response to training. These longitudinal magnetic resonance imaging (MRI) training studies examine learning-induced alterations in functionally relevant brain areas and interconnected structural networks in relationship with improvements in motor performance. In healthy adults, experience-dependent changes following motor skill training have been found in microstructure and macrostructure when triggered with only relatively short periods (in terms of weeks) of motor practice (Taubert & et al., 2010). Moreover, there is increasing evidence of plastic changes in brain structure in children as well. For example, Drijkoningen et al. (2015) has applied advanced diffusion MRI technology to sensitively track neuroplastic alterations in the cerebellar peduncles using PC-based portable balance control training programs (for two months) in young patients (aged 8 to 20 years) with traumatic brain injury and an age-matched healthy control group (Drijkoningen et al., 2015). Results revealed cerebellar white matter changes and improvements in dynamic aspects of postural control in both groups. A similar approach for enhancing structural neuroplasticity and motor control could also be implemented in children with DCD. One approach is to examine learning and development parametrically by looking at the dynamics of the interaction between task, context and the neuromotor system – a “hybrid approach”!

2. Perceptual-motor coupling and coordination

Wade frequently defers to the basic hypothesis that DCD is explained by a deficit in “perceptual-motor coupling” or “in the perception-action relationship”. This view, in fact, is more a global description of the kinematics of the condition than a causal explanation. It remains unclear exactly what this “hypothesis” means in terms of causality, or indeed, possible mechanisms even at the level of person-environment interactions. It remains the case that the arguments presented by Wade in this review do not extend much beyond a descriptive level of analysis. For example, possible mechanisms of perceptual-motor coupling are not entertained. Maturation and development of the neuromotor system itself must be a part of any such explanation, conceived of as an Individual level constraint on motor behaviour. Indeed, this may be a point of possible integration between explanatory frameworks. It is perhaps ironic that one of most important components of the individual system – the brain – rarely features in any ecological account of DCD. Rather, traditional ecological/dynamical accounts are largely concerned with the changing dynamics (both kinematic and kinetic) of the effector systems as a function of variations in task-environmental constraints; e.g., changes in rhythmic auditory-motor coupling as a function of the stimulus beat. On occasion, dynamical processes of this type are discussed in relation to neurocognitive mechanisms (Whitall et al., 2008).

The notions of *self-organisation* and *direct perception* are important and powerful postulates of the ecological approach but should not be immune to questions about mechanisms. If (causal) ecological accounts assert that DCD reflects a reduced ability to judge potential actions in relation to affordances or perhaps reduced coupling, the trick is to then work out why and how. For many children with DCD, development of efficient motor coordination and adequate levels of skill are elusive, despite ample experience or practice. Moreover, even basic processes of motor learning that are largely implicit have been shown to be reduced in DCD (Steenbergen, van der Kamp, Verneau, Jongbloed-Pereboom, & Masters, 2010). In our 2012 meta-analysis (Wilson et al., 2013) and an updated systematic review of work conducted between mid-2011 and September 2016, effect sizes for group (DCD vs. non-DCD) were large across studies, and across different paradigms. These effects cannot be ignored. Mapping possible underlying mechanism within a developmental framework is especially complex as the organism is constantly maturing and changing with experience—this is not reducible to box-and-arrow logic. The changing

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