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OPINION PAPER

The continued need for scientific monographs: an appreciation of John Rothwell's "Control of human voluntary movement"

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Abstract
Here I write a personal assessment of Professor John Rothwell's seminal book, "Control of Human Voluntary Movement". I focus on the second edition published in 1994, reflecting on its importance over the last 25 years and explaining why it remains highly relevant for the motor control field to this day. It is to be hoped that a third edition will be written that updates the physiology and unifies it with computational motor control. The book attests to the continuing importance of monographs in science, as they uniquely allow for long-form narrative and coherent synthesis.

Keywords Motor control · Movement · Monograph

Introduction

In the late 90 s and to the mid 2000s, while I was still junior faculty at Columbia University in New York, I was tasked with giving several of the motor system lectures to the medical students and neuroscience graduate students. Topics I covered included an introduction to motor control, spinal reflexes, posture and locomotion, the cerebellum, and motor and premotor cortex. This had become quite a famous course, I had also taken it as a medical student, because its lecture notes served as the basis for the textbook "Principles of Neural science". The first edition of the textbook had 468 pages and came out in 1981 and was edited by Eric Kandel and James Schwartz (Kandel and Schwartz 1991). The latest edition came out in 2012 with five editors and 1747 pages (Kandel and Schwartz 2012).

Every year, students found the motor section of the course the most difficult—the textbook chapters in particular. What is it about the study of the motor system that makes it daunting? I think that it is at least in part attributable to the fact that it is both comprised heavily of physiology and depends on disciplines that fall outside of traditional biology, including physics and biomechanics. Molecular biology apparently is more understandable to students than physiology; they are more comfortable with transcriptional promoters than the gain of the stretch reflex. Finally, current knowledge in the area is not easily summarized—we still cannot say definitively what the motor cortex, basal ganglia, or cerebellum do. There is still debate over what causes spasticity in limbs.

At some point in the late 90 s, I picked up the 1994 edition of "Control of Human Voluntary Movement", from here on referred to as CHVM (Rothwell 1994). CHVM has approximately 500 pages, and covers the physiology and anatomy of the motor system from muscles, through segmental reflexes and spinal pathways to the basal ganglia and cortex. Unlike the chapters on similar topics in "Principles of Neural Science", however, it was written by a single author!—John Rothwell. As a visiting medical student at Queen Square way back in 1992, I had watched his mentor David Marsden discuss motor disorders in patients. Like everyone, I was somewhat awed by Marsden and began to see where I wanted to go with my career. Incidentally, this is what Marsden had to say about CHVM: "The stimulus provided by this volume will be invaluable. Put it by the bedside with a red pencil and the ideas will flow." I knew that Professor Rothwell later took over the Human Movement and Balance Unit at Queen Square after Marsden's untimely death in 1998 and he made it into a beacon for the motor control field. Anyway, once I came across CHVM I devoured it. Then I read it again. I am still reading it.

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The first edition of CHVM came out in 1987 (Rothwell 1987). John tells me that he wrote it because his old tutor at Trinity College, Cambridge, Pat Merton (of the servo hypothesis), told him to—probably because he did not want to write it himself. It was around the same time that Merton had told John to give the lectures in the part II physiology course at Cambridge. John states that he had the temerity to include material beyond stretch reflexes, for example the basal ganglia, which he thinks may have disappointed Merton. John was clearly asking for trouble and found it in the form of having to write a book. This all has strange echoes for me, as I too was asked to give my mentor's lectures and then help to update the book chapters for the upcoming edition of "Principles of Neural Science". The second edition of CHVM (Rothwell 1994) was written, while John was on sabbatical in Sydney and things went more smoothly. There has been no third edition, even though one long-ago evening with John in Chicago over drinks at the Society for Neuroscience meeting, I offered to co-author it. I remember an expression of bemusement mixed with horror.

Why is the CHVM so good and still so necessary? First of all, it is a book. In the humanities, the book and the monograph remain the coins of the academic realm, whereas in the sciences, barely anyone reads books let alone writes them. Indeed, one could argue that the threat that the humanities currently face is only going to make future scientists even less likely to read books of any kind and thereby threaten their capacity for critical thought and synthesis. Instead, we read and write ever more compressed articles with a raft of supplementary materials attached (which no one reads). These salami slices of flash and hype are often expected to be reviewed in less than 2 weeks. Shamelessly, the fast and the shallow have been promoted over the slow and the deep. I have been told by an editor at a major academic press, that if one is going to propose a book, it should be in the popular science genre rather than a monograph. In this (anti) intellectual climate, the deep synthesis of the current state of scientific knowledge in a particular domain by a single author is, therefore, an act of both rebellion and necessity. Professor Rothwell wrote to me in an email that:

> "I think there is a sadly forgotten need for a good monograph by a single author every now and again. Papers have become scrappy pieces of the minimum quanta of information needed to get a publication. Multi-author reviews can try to bring things together, but the downside is that because they are written by committee they are bland. In fact, I'd say they suffer from cognitive dissonance since they manage to hold many opposing viewpoints at the same time. At least you ought to get a single coherent thread of thinking in a good monograph."

This impression is corroborated by a recent report on the role of scholarly monographs: "Writing a monograph allows the author to weave a complex and reflective narrative, tying together a body of research in a way that is not possible with journal articles or other shorter outputs." (Crossick 2015).

The second reason the book is so good is because Professor Rothwell is. He is one of the few people who had the depth and breadth of knowledge to pull it off; he had control of his material. He had published on reflexes, proprioception, descending pathways, cerebellum, basal ganglia, and motor cortex in health and disease; a list that is far from exhaustive. The third and most important reason the book is so good is because it explained a difficult subject lucidly within a coherent narrative (as compared to the fragmentary approach that is unavoidable in a multi-author textbook). It also provided a physiological counter balance at a time of a shift towards an emphasis on computational motor control, which began its rise in the mid-90 s. Unfortunately, a divide between psychophysical/computational motor control and physiological motor control is still with us to this day. Perhaps a new book is needed that brings these two approaches together.

Let's take a brief dive into the book. In the introduction, Professor Rothwell emphasizes the hierarchical nature of movement production by listing the following stages: (i) idea; (ii) motor plan; (iii) execution of programme commands; (iv) move. The stages in this sequence form a hierarchical chain of command, from the abstract concept of moving, to the practicalities of contracting the right muscles at the right time." He explains his hierarchical notion by making the computer analogy of an overall controlling program that can omit details because these are taken care of by subroutines lower in the hierarchy, which in turn have sub-routines and so on ad infinitum.

His book chapters essentially proceed backwards through the above-listed sequence beginning with the lowest level of movement granularity, the muscles. He then moves on to the motor unit, proprioception and kinesthesia, reflexes, ascending and descending pathways, and posture. The final three chapters cover the cerebellum, basal ganglia, and cortex.

The last section of the introduction begins with the statement that "Most of the ideas of movement control were developed intuitively by the great clinical neurologists of the last century. They remain essentially the same today even when dressed up in the latest computer jargon." I have a great deal of sympathy with this point and find how he weaves pathophysiology into the book of immense and lasting value. That said, we again see the tension between physiological and computational views of motor control. At the end of this section, John almost apologizes for the separation of the movement control system into chapters as he states: "there is no simple answer to the question "what does the cerebellum/basal ganglia do?" simply because neither structure ever does anything on its own." This is very much a physiologist's view as indeed for a particular motor behavior, the components of the hierarchy must come together like a conductor and the orchestra. The computational view of the motor system, in contrast, does consider it useful to assign computations to particular brain structures. For example, Kenji Doya's now famous tripartite division of assigning reinforcement learning to the basal ganglia, supervised learning to the cerebellum, and unsupervised learning to the cortex (Doya 1999).

Chapter 6, titled "Investigating reflex pathways and their function" had a great influence on me. For example, in the section in spasticity in humans, he describes an experiment with torque motors, which showed that hyperreflexia is present at rest but not during movement. He states: "The fact that tone is increased at rest means that disorders of tone in spasticity cannot contribute to the difficulties that these patients have in making voluntary movements." This insight sadly has not prevented profligate use of botox. Another part of the book that had a lasting influence on me was the section titled "Lesions of descending pathways in humans and monkeys". Here, John gives a cogent summary of the classic monkey pyramidotomy experiments by Lawrence and Kuypers and talks about the differences in the effects on arm and hand motor control of cortical, capsular and pyramidal tract lesion in humans. Later he discusses the role of premotor cortex lesions on the production of spasticity—a question that has yet to be resolved. It is a concern that it may never be as monkey experiments of this kind are increasingly rare, both for ethical and economic reasons.

In Chapter 10 on the cerebellum, Professor Rothwell makes the following statement: "When we imagine what is meant by motor learning, examples such as riding a bike or playing the piano spring to mind. Unfortunately, these are extraordinarily complex tasks, and as such are very difficult to analyze in detail. When physiologists examine motor learning, they are usually tackling something a little more prosaic. Very often, this involves adaptation of motor commands to small changes in the environment." This was written 25 years ago, but adaptation experiments are still very much alive (or a bit zombified) today. Indeed, I and others have written extensively on whether adaptation experiments are useful for understanding motor learning when it comes to more complex tasks.

Needless to say, a lot has changed in 25 years. For example, much has been learned about post-stroke synergies and the likely role of the reticulospinal tract. Where the quarter-century gap is most apparent; however, is in the chapters on the cerebellum, basal ganglia and cortex. In the cerebellar chapter, there is no mention of forward models. In the basal ganglia chapter, there is no mention of reinforcement learning, reward prediction errors or vigor. This omission is somewhat understandable as the seminal findings of Wolfram Schultz and colleagues were coming out just before and after the publication of the second edition of CHVM. In the cortex chapter, the paradigm shift to population codes, the dynamical systems view and neuronal state spaces had yet to occur. Finally, there is very little in the book on possible mechanisms of recovery of motor control after lesions to the nervous system.

Nevertheless, from the standpoint of early 2020, the book remains of great value in terms of form—it reveals the continuing need for thoughtful synthesis by an intellectual leader. It also remains an essential reading in terms of content although perhaps with slightly diminishing returns as the book proceeds up the neural axis from the standpoint of current theories of normal function. The sections on pathophysiology remain invaluable throughout. I recommend that anyone with an interest in motor control still read it or at least peruse it carefully. From a personal standpoint, I remain forever grateful to Professor Rothwell for writing it as it has had a great influence on my career and inspired me to co-author a book. I was not up to a monograph (Krakauer and Carmichael 2017).

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