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ARTICLE

The intelligent reflex

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ABSTRACT
The seeming distinction between motor and cognitive skills has hinged on the fact that the former are automatic and non-propositional (knowing-how), whereas the latter are slow and deliberative (knowing-that). Here, the physiological and behavioral phenomenon of long-latency stretch reflexes is used to show that "knowing-that" can be incorporated into "knowing-how," either immediately or through learning. The experimental demonstration that slow computations can, with practice, be cached for fast retrieval, without the need for re-computation, dissolves the intellectualist/anti-intellectualist distinction: All complex human tasks, at any level of expertise, are a combination of intelligent reflexes and deliberative decisions.

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1. Introduction

Motor skills are greatly admired across cultures, as is attested to by the fact that half the world's population watched the recent World Cup final. That said, philosophers and psychologists have long been conflicted over whether or not to consider the acquisition and performance of motor skills to be comparable to that of cognitive skills. Results in cognitive neuroscience, starting with the seminal case of the amnestic patient HM, have been taken as evidence of a fundamental dissociation between knowing-that and knowing-how (Devitt, 2011; Stanley & Krakauer, 2013; Wallis, 2008). The perceived division between the intellectual and the practical permeates our culture, as in the notion of working with one's hands, which implies less reliance on the mind, and the pervasive myth of the dumb college jock, to name two examples. On a personal note, back in 2013, I was interviewed by a journalist for Time magazine who was writing an article about Lebron James. The title of the article was "Basketball Einstein: The genius of LeBron." The title was meant to play on the seeming incongruence of calling the six-foot-eight muscular athlete a genius comparable to Einstein. Here is the opening paragraph of the article, which captures much of what is at stake in the philosophical and scientific debate:

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> LeBron James is a genius. You may be thinking that "genius athlete' is some kind of contradiction. Suggesting that athletes are as cerebral as physicists solving cosmic mysteries or as creative as modern-day Mozarts seems like a stretch. LeBron James is LeBron James because he's a chiseled, large, freakishly fast specimen who has mastered the fundamental skills of basketball: dribbling, shooting, and passing. Big muscles require no genius. Let's reserve that term for brainiacs. (Gregory, 2013)

There is not the space to detail all the zigs and zags of this longstanding anti-intellectualist argument, which dates back to the ancient Greeks (*techne* versus *episteme*) and continues into the present day. Instead, here the focus will be on two related assumptions or misconceptions that I perceive as causally linked to the persistent confusion. The first is that propositional knowledge is not needed to learn and perform skilled or over-learned actions. The second is that, because there are automatic or reflexive components to performance at the highest level of motor skill (expertise), an athlete is seen as a creature of habit in contrast to the ever-thoughtful philosopher or theoretical physicist. I will make a crucial claim right here at the outset. The claim is that all the longstanding perceived divides between the theoretical and the practical, the cognitive and the motor, and the use of one's hands versus the use of one's brain are related to the philosophical difficulty posed by the non-deliberative character of expertise *tout court*. That is to say, there is a more fundamental dichotomy at the heart of the confusion than the one between action and thought.

A much-used example in the philosophical and psychological literature on acquired skill is the game of chess. The late Hubert Dreyfus, along with Gilbert Ryle, is perhaps the philosopher most associated with the anti-cognitivist stance, and he stated, with regard to chess, that "fortunately, the expert usually does not need to calculate. If he has had enough experience and stays involved, he will find himself responding in a masterful way before he has time to think" (Dreyfus, 2014). Support for this view came from later studies that showed a correlation between IQ and chess skill in young players learning chess but *no* correlation between IQ and the ranking of master chess and Go players. As the psychologist Anders Ericcson points out in a recent summary of these studies (Ericson and Pool 2016), this seeming contradiction can be resolved if one distinguishes between the general fluid intelligence needed to initially understand the rules of chess and deliberate over how to first apply them (as would be the case in young players), and practice-accrued mental representations – "mental shortcuts" that preclude the need for deliberation. As Ericsson states:

> With enough solitary practice, the mental representations become so useful and powerful in playing the game that the major thing separating two players is not their intelligence – their visuospatial abilities, or even their memory or processing speed – but rather the quality of and quantity of their mental representations and how effectively they use them.

This is indeed very close to what Dreyfus and Dreyfus write: "The expert is simply not following any rules! He is doing just what Socrates. . .feared he might be doing – discriminating thousands of special cases" (Dreyfus & Dreyfus, 1984). As we shall see later, this is exactly the case we have recently made for motor skills: They are comprised, in part, of practice-induced, cached policies that are stored in a look-up table for fast retrieval (Haith and Krakauer 2018). Thus, the cognitive-motor divide is actually a surface manifestation of a more fundamental dichotomy between the deliberative and the procedural. Indeed, a strong clue to the lack of a qualitative difference between motor and cognitive skills is their very similar requirement of many years of deliberative practice in order to be mastered (Ericsson & Pool, 2016). Nevertheless, in its pure form, the anti-cognitivist position remains untenable for motor skill in particular and for all forms of expertise, motor and non-motor, in general. This is because all experience-dependent tasks that humans engage in, even at the expert level and perhaps even especially there, result from the combination of purposeful goal-directed behavior, which relies on propositional knowledge and deliberation, and practice-induced automatized responses. This is true for tennis and driving, and it is true for poetry and mathematics. Serena Williams is no more just a bundle of habits than Jane Goodall is. To demonstrate this, I will describe recent work on a particular class of sensorimotor reflexes which shows how they can be acquired with learning. There is some irony in the fact that a return to the study of the motor system can perhaps heal a divide that, in fact, transcends the one between motor and non-motor skills.

The emphasis here is on practice because it is the way to transform voluntary responses initially based on deliberative decision-making into automatic responses available for rapid retrieval, so the subject does not need to think about them again. The argument here is in no way altered by the undeniable existence of fast, goal-directed responses that have *always* been implicit, for example, hunting behaviors triggered in a kitten the first time it sees a bird. It may be the case that purposeful behaviors can ultimately be stored and retrieved in a similar way as innate goal-directed responses are, but it is the differences in their *origins* that is of critical importance here. Thus, the core idea that will be introduced here, backed up by empirical evidence, is that propositional knowledge can, as suggested by Dreyfus, be transformed into goal-directed, automatized responses – *intelligent reflexes*. That is to say, any component of a motor task starts with a knowledge-based scaffold with associated intelligent deliberations which, through practice, are transformed into control policies that are then cached for subsequent fast retrieval without there being a need to rethink them again. What do we mean here by intelligence? For the purposes of this article, we mean actions that are flexible and goal-directed. A control policy is a goal-dependent mapping or a set of rules between the state of the body and its motor commands. Note the similarity in form between this more complex mapping and the simpler sensory-input-motor-output structure of the stretch reflex: They are both rapid and non-deliberative. It is this similarity in form that allows the use of the term 'intelligent reflexes.' Sometimes habits and reflexes are used interchangeably in everyday language, but they are not, in fact, synonymous. A response is considered habitual when it's evinced regardless of context, and this response can occur at any latency. Reflexes and habits do, nevertheless, share a very important similarity: They are automatic responses that can be constructed through initial cognitive scaffolding and practice. In essence, reflexes and habits retain evidence of a past intelligence that is "baked into them" so that this intelligence does not need to be reassembled every time they are used.

2. Long-latency stretch reflexes

The concept of the reflex is central in the history of neuroscientific thought (Clarke & Jacyna, 1987). It is of interest in the context of this essay because reflexive behavior has been and continues to be contrasted with voluntary behavior. The reflexive-voluntary dichotomy is in many ways a physiological analog of the thought-action dichotomy, even though this one concerns two kinds of movement. That is to say, as was pointed out above, just as the distinction between the deliberative and procedural exists *within* the cognitive domain, it also exists, in a slightly different form, within the motor domain. Traditionally, reflexes have been defined as invariant stereotypical responses time-locked to a stimulus. The most famous and the most studied example is the stretch reflex, in which the stretching of a muscle initiates a short-latency monosynaptic response (from spindle afferent to motor neuron in the spinal segment) that acts to resist the stretch.

In contrast to largely unmodifiable stereotypical simple reflexes, voluntary behaviors are flexible and have "freedom from immediacy" (Shadlen & Gold, 2004). This reflexive-voluntary distinction has also been mapped onto a hierarchical notion of the nervous system, specifically, the brain versus the spinal cord. For example, Marshall Hall, a 19th century physiologist and neurologist who played a foundational role in the introduction of the reflex concept, considered the reflex to be "a purely mechanical phenomenon entirely distinct from the mind." In his memoirs, he made it clear that reflexes are confined to the spinal cord, whereas voluntary movement and the intellect are attributable to the cerebral system (Clarke & Jacyna, 1987). Here one can hear echoes of the concerns that opened the article on Lebron James, mentioned at the beginning of this chapter: Isn't being good at basketball just about having good muscles and reflexes? Interestingly, the fact that playing basketball is obviously a voluntary act does not seem to alleviate this cultural bias. It is as if the whole motor system is a giant reflex machine. Indeed, the noted early-20th-century physiologist Charles Sherrington, while acknowledging that "pure reflex action itself cannot be seen to cover such extensive ground as do the instincts actuated by 'urges' and 'drives,'" nevertheless claimed that a "train of motor acts results from a train of successive external situations" (Sherrington, 1906/2017). Within this chained-reflex framework, the credit for Lebron James' success goes to his motor system, which produces a superior read-out in response to external stimuli. Needless to say, this dichotomy, like the principal dichotomy in this chapter, does not hold up to scrutiny. I will argue that the alternative conception of reflexes that I outline lends support to the idea that all learned skills are a combination of cached computations and conscious deliberation. Indeed, this dichotomous view of motor skills is recapitulated across all cognitive domains and is the basis for the system-one-versus-system-two idea put forward by Kahneman, for example (2011).

The best way to start a discussion about motor skill as, in part, the assembly of intelligent reflexes is to first describe the taxonomy of reflex responses. If one's arm is resting on a stable surface and is mechanically perturbed by an external-force pulse, then a stereotypical sequence of muscle activity is triggered, starting with the short-latency stretch reflex (at 20–50 ms), much loved by neurologists with their hammers, and ending with a voluntary response (>100 ms). It is what lies between these two responses that is of interest here. As stated by Andrew Pruszynski and Stephen Scott in a comprehensive review, "occurring between these two events is the enigmatic and often studied long-latency stretch reflex (50–-100 ms), which occurs earlier than standard metrics of voluntary reaction time yet can sometimes be modified by a subject's voluntary intent" (Pruszynski & Scott, 2012). It is interesting that Gibert Ryle's famous paper "Knowing-how and knowing-that" was published in 1945 (Ryle, 1949), and long-latency stretch reflexes were first described by Peter Hammond in 1955 (Hammond, 1955). I am not aware of a previous work that has explicitly brought these two mid-twentieth century lines of inquiry together. Pruszynski and Scott go on to comment that the "duality of the long-latency reflex, which is, on the one hand, fast, simple, and automatic like the short-latency reflex and, on the other hand, complex and capable like voluntary control, has yielded a great deal of debate about its functional role in motor behavior and its underlying neural circuitry" (Pruszynski & Scott, 2012). What is so fascinating is that this strictly scientific debate directly parallels the intellectualist versus anti-intellectualist debate on knowing what versus knowing-how in the philosophy of skill. More importantly, in my view, the science solves the philosophical debate surprisingly easily. To bolster this statement, I will give some examples of intelligent long-latency reflexes.

In a famous experiment conducted in 1981 (Marsden, Merton, & Morton, 1981), David Marsden and colleagues had subjects crouch whilst holding onto a handle with their left hand, which could suddenly pull them off balance. The crucial manipulation was with the right arm. In one case, subjects braced themselves by holding on to a table, and, in the other case, they held on to a tea cup (in reality, the experimenters began with a cup of tea but then customized the apparatus). The interesting result was that when the handle was pulled, the long-latency reflex in the right elbow extensor was activated for the table but reversed for the tea cup. This is intelligent involuntary behavior because activation of the reflex aids stabilization when holding onto the table and reversing it keeps the tea from spilling. About this result, the authors of the study write the following:

> It thus proves, as conjectured, that the crossed arm can make at least two different types of automatic postural response, one when it is in use to steady the body, the other when it is holding a cup of tea or some such object; and that the choice between the possible reactions (which may or may not agree with the subject's conscious notions of what is appropriate) is also made at a subconscious level.

Thus, the behavior is contextually intelligent *and* automatic. Many similar results have been described in the years following this experiment. An illustrative, more recent example was provided by Stephen Scott and colleagues (Nashed, Crevecoeur, & Scott, 2012). In their experiment, subjects were asked to make planar reaching movements toward either a small, circular target or a long, rectangular target. They were then unexpectedly perturbed and bumped off course. In the case of the circular target, they demonstrated a corrective reflex response that redirected them to the target, whereas, in the case of the rectangular target, they went with the perturbation. Subjects *knew* the shape of the target, but, then, they generated a response that they did *not* know they were going to make. Is this a knowing-that or a knowing-how task? The answer is both.

3. Learning and practice

Of direct relevance to this discussion on motor skill is the fact that intelligent goal-directed automatic responses can also be learned. In the cases of the triggered hunting control policy in the kitten mentioned previously and the two experiments described above, the responses are contextually triggered but immediately available. Alternatively, however, one can acquire task-specific long-latency reflexes and more complex control policies through learning over many trials (Ahmadi-Pajour et al., 2012; Franklin & Wolpert, 2008). This is crucial as it shows that responses for novel tasks that initially require verbal instruction and conscious deliberation for performance can become automatized with learning. A very intuitive example is learning your ATM number. At first you need to be given the number, and typing it is slow the first few times as you silently think through the four-number sequence. At some point, your fingers just do it. I can no longer recite one of my ATM numbers, but I can type it out effortlessly. Indeed, the transition from deliberation to automaticity I describe here is almost certainly what happened in the famous case of the amnesic patient HM. He was instructed on how to mirror-draw, and then, with practice, he was able to automatize the ability to the point that, even though he had no explicit recollection of how he had originally learned it, he retained the ability across days (Milner, 1962). The case of HM, which has often been taken as evidence for the difference between motor skills and conscious deliberation, in fact demonstrates the opposite, namely, that all tasks are a combination of conscious deliberation (i.e., "I must sit down here and pick up this pencil and mirror-draw") and subsequent automatic execution (i.e., automatic mirror-drawing). The critical point I make here is that *all* tasks that require weeks, months, and years of practice are like this, whether they be tennis, chess, or French. They will always have deliberative and automatic pieces that are hierarchically assembled in task space and in the neuroaxis.

4. Conclusion

Where does this leave us with respect to "knowing-that" and "knowing-how"? At issue always seems to have been the apparent incompatibility between the automatic and the deliberative. Through the lens of reflex physiology and the learning of intelligent policies, however, the incompatibility just goes away. There really is no divide between, say, Gilbert Ryle and Hubert Dreyfus on the one hand, and Jason Stanley and Carlotta Pavese on the other (Pavese, 2015, in press; Stanley, 2011). It all just depends whether the component of the behavior being considered is currently deliberative, was deliberative in the past and then automatized, or was always automatic. That is to say, all actions can go through this transition from deliberative to automatic, or they are innate. Indeed, Ryle himself understood these distinctions: His clown can *deliberately* trip now because he learned how to trip in the past and automatized the skill. The longstanding intellectualist/anti-intellectualist debate originated before there was scientific evidence showing that almost any deliberative propositional content can be automatized. For example, these are part of the instructions for juggling:

> Start by throwing the ball in the front of your right hand in an arc to your left hand. When ball (1) reaches its highest point, throw the ball in your left hand (2) in an arc to your right hand. Catch (1) in your left hand. This is like the two-ball exercise. (How to Juggle 3 Balls - YoYoGuy.com http://www.yoyoguy.com/info/ball.html)

These instructions clearly have the form of knowing what juggling requires. Through practice, this knowing what automatizes into knowing-how. Ascribing to this view does not, however, require a commitment to a "just do it" view of motor expertise. Instead, it holds that the performance of any motor skill, even at the expert level, will consist of the combination of deciding to select and initiate the right action in a given context with rapid retrieval and execution of the appropriate control policy or automatized response. This combination is akin to being able to decide whether to swallow a pill, but the sequential swallowing mechanism then proceeds automatically and involuntarily. This dyadic relationship between deliberation and automaticity never goes away, but there is no conflict between them because they are usually operating at different hierarchical levels: the level of explicit goals versus the level of implicit goals. For example, my explicit goal might be to get from A to B, and I may decide to run along the top of a narrow, high wall to do so. Implicitly, to avoid falling, short-latency anticipatory postural adjustments (intelligent reflexes) are in operation. All tasks and behaviors can be similarly organized into levels of hierarchical abstraction; these can be assembled through practice and exist as distributed representations across the anatomical levels of the nervous system.

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