Tacit knowledge: unpacking the motor skills metaphor

Stephen Gourlay

Kingston Business School,
Kingston University, UK
gourlay1@kingston.ac.uk

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Stephen Gourlay

Kingston Business School,
Kingston University, UK
gourlay1@kingston.ac.uk

Abstract

Motor skills are held to provide paradigm examples of tacit knowledge but knowledge management researchers have overlooked decades of research and theorising on motor skills. A review of this field shows it to be undergoing considerable intellectual debate between information-processing and dynamic systems models. The former support the notion of tacit knowledge, but dynamic systems models do not, nor do emerging multi-level models. Some implications for knowledge management research and practice are outlined.

Keywords: tacit knowledge; motor skills; representations; information processing; dynamic systems

Introduction

It is widely agreed that tacit knowledge is important to organizations and to the theory and practice of knowledge management. Nonaka and his colleagues make it central to their model of organizational knowledge creation (Nonaka & Takeuchi, 1995). Baumard (1999, p. 8) argued that it is critical both to daily management, and as a firm's source of competitive advantage (see also Spender, 1996, Ambrosini & Bowman, 2001), a notion that complements Nonaka's emphasis. Tacit knowledge transfer is regarded as particularly problematic since it can only be 'embedded' in people and culture (Argote & Ingram, 2000).

On the other hand it is a difficult concept; it resists operationalization (Ambrosini & Bowman, 2001; Spender, 1996) and carries too many meanings. Spender (1996) distinguished conscious, automatic, and collective practical knowledge as three types of tacit knowledge. A recent review of empirical phenomena to which the label tacit knowledge was applied identified six distinct ways in which the phrase has been used, excluding 'collective' references (Gourlay 2004a). Claims that tacit knowledge cannot be examined empirically because it is unconscious (Easterby-Smith & Lyles, 2003), or that it is ineffable (Tsoukas, 2003) only lend support to Donaldson's (2001) charge of mystification.

Reviewing applications of the term to empirical observations is one way to clarify the meaning of the term. Another is through conceptual critique, interrogation of sources, and philosophical debate – after all, the phrase emerged from Polanyi's various philosophical writings (e.g. Polanyi, 1962; 1966). Gourlay (2004b) explored some of Polanyi's writings, and concluded that we have failed to notice he wrote principally about tacit *knowing*, a process, and not a form of knowledge. In fact, within Polanyi's framework, there is little or no room for the idea of a kind of *knowledge* that is tacit. Others (e.g. Janik, 1988; Tsoukas, 2003, and Collins, 1974, 2001a) have drawn inspiration from Wittgenstein, but recently Pleasants (1996) argued that Wittgenstein's philosophy is wholly inimical to the idea of a personal knowledge on the lines Polanyi endorsed. It seems we are unlikely to progress much along this route.

This paper takes a different approach, trying to 'unpack' the notion by exploring research into a class of behaviours loosely labelled as 'motor skills'. After making the case for this approach, the paper reviews the major conceptual approaches found in this broad field, and in conclusion, draws out some implications for the concept of tacit knowledge as regards motor skills.

Why "motor skills"?

Tacit knowledge and motor skills

The reason for focusing on motor skills is simple: they "supply a set of paradigmatic examples of tacit knowledge in everyday life" (MacKenzie, 1996, p. 215) and bicycle riding is a particularly good example because, Collins argues, even if we could formulate rules for riding a bicycle, they would be of little use to a non-rider (Collins 2001a). The prominence of bicycle riding is due to Polanyi who wrote that "If I know how to ride a bicycle or how to swim, this does not mean that I can tell how I manage to keep my balance on a bicycle or keep afloat when swimming." (Polanyi, 1969a, p. 141). In *Personal Knowledge* (1962, pp. 49-50) he noted that "the principle by which the cyclist maintains his balance is not generally known" but, went on to describe in detail that cyclists maintain their balance by steering *in the direction* of imbalance, thus correcting it. Later he was more explicit writing that "in order to compensate for a given angle of imbalance *a*, we must take a curve on the side of the imbalance, of which the radius (*r*) should be proportionate to the square of the velocity (*v*) over the imbalance"

(Polanyi, 1969, p. 144). Since successful cyclists evidently know these facts, but are unable to articulate it, this knowledge is tacit.

We might well ask how Polanyi could give such accounts if this knowledge was tacit? He cited no sources for his information, and we have simply been left with his authority on the matter. He was right that little was known about bicycle riding as a review of research written in 1979 only found 21 papers of which only four dealt with the rider's contribution to control (Doyle 1988). However, Polanyi was completely wrong in his account of how cyclists ride and keep their balance.

Doyle (1988) conducted one of the rare studies of bicycle riding, and confirmed that riders do not have a clear idea of what they are doing. When it comes to turning corners he noted most riders believe they initiate a turn by turning the handle bars in the direction they wish to go (as Polanyi wrote). In fact, however, the opposite is the case, as he showed by observing the marks made by wet tyres on a dry surface: "If we enter a turn quickly ... we can see that the front wheel turns momentarily away from the desired direction before making the turn ..." (Doyle, 1988 p. 26).

Polanyi appears to have been mistaken – along with most others – in his account of how bicycle riders maintain balance while cornering. This is important because while he says that knowledge of the explicit rule would not be of use to a cyclist, he claimed that a rule such as he described is actually followed, which is not the case. From one perspective this merely deepens the mystery: Polanyi believed he had formulated the tacit rules for maintaining balance on a bicycle when in fact he had done nothing of the sort – the rules remained tacit! On the other hand it illustrates some of the problems with assertions about tacit knowledge, namely, that while it is often invoked as an explanatory factor, there is usually absolutely no evidence to support the claim, and its use actually amounts to little more than a re-labelling of a problem. In the case of bicycle riding, it may not be necessary to invoke the idea of tacit rules/knowledge at all (Doyle 1988).

Motor skills – the field(s)

The term "motor skills" is used in this paper for convenience, and because it is familiar in management and organization studies' circles. Gallahue and Ozmun's textbook (1998, pp. 17-18) defines motor, motor learning, behaviour, control and development as well as movement, movement pattern and movement skill, but not motor skill.

However, it is clear that, broadly speaking, motor skills in the sense Polanyi and others writing about tacit knowledge used it refers to the fields covered by these terms.

Laszlo (1992), referring to motor control, lists a number of pertinent disciplines, including anatomy, physiology, psychology, human movement science, bioengineering, education, neurology, and sport medicine. Comprehensive as the list seems, Laszlo omits cognitive science, kinaesology (Abernethy & Sparrow, 1992), motor development (Gallahue & Ozmun 1998); motor behaviour and skill (Kelso 1982a); and movement behaviour (Summers, 1992). This is not to criticize Laszlo, but to underscore her point that the field as a whole is vast and multi-disciplinary, and one that few if any people can actually bridge. This can cause difficulties and misdirected effort. For example, psychologists largely failed to take account of research on central nervous system functioning in the 1970s which showed that "the classical view of strict separation of motor and sensory areas in the cortex was incorrect" (Laszlo, 1992, p. 48).

Addressing the motor control/skills field, Laszlo argued that "if we are to arrive at a unified body of knowledge of how movements are controlled and skills acquired, and guard against promulgation of theories in our own discipline which conflict with facts which have been established outside our own field." (1992, p. 48), then we have no alternative but to try to draw together these diverse bodies of knowledge. This clearly expresses the sentiments motivating the present paper.

If the task of synthesis of research relevant to motor skills is difficult for people working within one of the sub-disciplines, it is perhaps even more difficult for someone like the present author coming from an entirely different background, a niche region (management and organization studies) of the social sciences. The task of being a stranger in a foreign land seeking to understand local culture and bring back some useful (and not mis-understood) nuggets for management studies is made easier than might at first seem. First, motor skills' studies entered a paradigm crisis in the 1980s which is apparently still unresolved, as a result of which several of the natives were driven to reflect on their discipline as a whole making it easier for an outsider to understand. Second, it turns out that much of the discussion reflected parallel debates in the behavioural and cognitive sciences. Thus motor skills' debates, at least at a level appropriate to the present paper, may not be too foreign after all.

While there is general agreement on the existence of a paradigm crisis there is no agreement on the names for the paradigms. Thus we find the labels computational, top-down, cognitive, constructivist, indirect, information-processing, prescriptive, and movement systems approaches contrasted with dynamic systems, bottom-up, ecological, action systems, and emergent perspectives (Goldfield, 1993; Burgess-Limerick, Abernethy & Limerick, 1994; Williams, Davids, Burwitz & Williams, 1992; Handford, Davids, Bennett, & Button, 1997; Summers, 1992; Abernethy & Sparrow 1992). On a more philosophical plane the conflict has been described in terms of indirect versus direct realism (Carello, Turvey, Kugler & Shaw 1984). In the absence of a consensus the terms information-processing or cognitive approaches, and dynamic/ecological systems approaches are used here since these labels indicate essential and contrasting features of the two paradigms.

Tacit knowledge in motor skills' research

Before examining the different paradigms in motor skills research it is worth noting that the attention of motor skills researchers has been drawn to the concept. In 1990 Davids and Myers reviewed research on complex work systems, as well as Polanyi's writings, that highlighted the significance of "an often indefinable and implicit level of knowledge" (p. 273), tacit knowledge. They argued that movement performance studies had neglected this and urged that greater priority should be placed on understanding how tacit knowledge develops. Their call appears to have fallen on deaf ears since only one other paper in the field has used the term (Blais, [1993], found too late to be reviewed here) and Davids and Myers' paper has rarely been cited. While this clearly suggests that researchers in this field do not find the term useful, it does not mean that the concept is absent from their theories. The review of the main paradigms will show whether this is the case or not.

Motor skills research – a historical outline

The study of movement control, at least by psychologists, dates from the late 19th century, but it was only with the development of the information-processing approach during the 1950s and a shift from focusing on movement products to movement processes that modern research and understanding began to develop (Pew & Rosenbaum, 1988; Kelso, 1982a). In the late 1960s there were still only two specialist journals (Abernethy & Sparrow, 1992) and it took until the 1970s for an institutionalized academic approach to human movement studies to began (Bootsma & Hardy 1997).

Using content and citation analysis of the *Journal of Motor Behavior*, Abernethy and Sparrow (1992) demonstrated that during the 1970s three related groups of theories dominated research, all of which are information-processing theories. From the early

1980s these were increasingly challenged by dynamic systems approaches which had become the dominant paradigm by the 1990s (Gallahue and Ozmun, 1998). It remains unclear, however, to what extent this shift is complete, as arguments from a computational (i.e. information-processing) perspective continue to be made (Wolpert, Ghahramani & Flanagan 2001). Moreover, talk of a rapprochement (e.g. Summers, 1992; Pressing, 1999; Abernethy, Hanna & Plooy, 2002) raises the question of whether or the differences really are fundamental.

Information processing or cognitive approaches. The first testable model of motor control was Adams' closed-loop feedback model (Stelmach, 1982; Williams, Davids & Williams, 1999). Adams proposed that movement was controlled by an internal comparison between incoming information about the ongoing movement, and stored information formed during previous successful movement. Thus deviations from the goal could be detected, and corrections made (Abernethy & Sparrow 1992; Stelmach 1982).

The closed-loop approach could explain the control of slow movements, where there was time for receipt of incoming information and its processing. It could not account for rapid movements, such as characterise many sports as well as more natural movements, where movement time occupies less than the available feedback time, given the processing constraints of the nervous system (Abernethy & Sparrow 1992; Schmidt 1982a). Nor could closed-loop models explain how people could produce movement in the absence of feedback information (Abernethy & Sparrow 1992).

By the mid-1970s closed-loop based research was giving way to open-loop models and the idea of a motor program to control movement in which Schmidt was a leading figure. One way of explaining how it is possible for people to complete movements before there is time for feedback processes to be effective relies on the idea that "subjects structure their movement in advance, and this structure is termed the *motor program*." (Schmidt, 1982a, p. 196; his emphasis). Early definitions of motor program implied that organisms must possess a vast number of programs in order to account for all an individual's actions, which raised problems about storage, and about the acquisition of novel actions (Schmidt, 1982b). In the face of continuing observational anomalies Schmidt advanced the idea of the generalized motor program or schema model of motor control (Abernethy & Sparrow, 1992; Schmidt, 1982a, b).

The schema model proposed that with experience essential rules about the relations between the acting organism and its environment would be abstracted and stored, thus providing a flexible framework for guiding movement (Abernethy & Sparrow, 1992). Such a “generalised program” (Schmidt, 1982b, p. 221) solves both the storage and novelty problems at the same time. However, attractive as the idea is, it has received only equivocal evidential support (Abernethy & Sparrow, 1992). If there are stored invariants of given classes of movements we would expect an experienced athlete, for example, to show little variation in gait or footfall when executing the run-up to a jump. Experiment and observations show that in fact there is considerable variation from one run to the next (Williams, et al., 1999; Handford et al., 1997).

The information processing approach models the workings of organisms on the analogy of a computer program (Pew & Rosenbaum, 1988; Williams et al., 1992) placing particular emphasis on the notions of internal representations, and computational processes (the means whereby representations are formed) (Pew & Rosenbaum, 1988). Following Meijer (1988, quoted in Williams et al., 1992, p. 165; see also Williams et al., 1999) information processing models assume organisms receive meaningless input stimuli that they convert via internal processes into meaningful representations that guide movement. Representations are a particularly important in this approach being internalized knowledge structures or programs recording movements (Williams et al., 1992; Handford et al., 1997). Philosophically, the approach is consistent with the ideas of indirect realism (Carello et al., 1984) or representational realism (Burgess-Limerick et al., 1994).

While information processing models proved useful in stimulating research in this field, as elsewhere, from the mid-1980s they were criticised on a number of grounds. In sports science, anomalous observations and doubts about the ecological validity of the laboratory based experiments that dominated information-processing based research in sports research led to some unease (Williams et al., 1992). Carello et al. (1984) questioned the principle of applying computer models to living systems arguing that as the former are determinate systems (being strictly bound by their initial conditions) and living systems are nondeterminate, being only loosely bound by initial conditions, the computer model is wholly inappropriate. Furthermore, discrete symbol systems, such as computer systems, are based on representations which themselves are abstractions from dynamic systems. Thus there is an error of logic in attempting to model the latter on the former. The notion of a program, and representations, also implicitly invokes the notion of a user ‘internal’ to the organism, a problem entailing an infinite regress (Kelso, 1982b). It was in this general context of the continued inability of information processing models to cope with new observations, and critiques by authors such as Kelso, Kugler, and Turvey, amongst others, that dynamic systems approaches were proposed, and rapidly came to dominate research.

Dynamic/ecological systems approaches. One particular problem information processing approaches faced was the degrees of freedom problem (Smith & Thelen, 1993). Turvey, Fitch and Tuller (1982) pointed out that on a conservative estimate of the number of muscle motor units involved in moving the human arm requires regulation of 2600 degrees of freedom. Assuming that only the joints needs regulating reduces the problem to the control of seven degrees of freedom, but even this, they argue, would be very difficult for a computational system. Moreover, this only covers a small part of the degrees of freedom problem, for the 'same' movement is not always produced in exactly the same way internally, and account still has to be taken of the varied contexts within which movements occur yet are functionally the same for the organism (Clark, Truly & Phillips 1993).

Dynamic systems approaches were able to provide explanations, and to inform experimental studies, for these kinds of problems. According to Abernethy and Sparrow (1992) some of the strongest evidence supporting these approaches came from studies of bimanual linkage, the production of speech, and transitions between different forms of gait that relied entirely on modelling the physical properties involved in the movements. An increasingly dominant view in the motor control literature on the transition from walking to running, for example, views "gait as a self-organised system with transitions between the walking and running gaits as automatic consequences of the collective structure of the human neuro-muscular-skeletal system" (Abernethy et al., 2002, p. 256). Movement coordination is thus seen as a consequence of the relationship between the physical nature of the body, and the environmental constraints (and opportunities) in which it moves (Burgess-Limerick et al., 1994; Thelen & Smith, 1994).

The dynamic systems approach in motor skills research was inspired by a number of developments including ecological psychology, and work on coordination and control (Abernethy & Sparrow 1992; Williams et al., 1992), that were merged to become what some call the "action systems" perspective (Williams et al., 1992, p. 163; see Reed 1996). These approaches share a number of common features and assumptions: direct realism; rejection of mind/matter, organism/environment and other dualisms; rejection of the need for representations; and the assumption that the appropriate unit of analysis must be the organism in its environment wherein both organism and environment are mutually constraining (Williams et al., 1992; Williams et al., 1999; Burgess-Limerick et al., 1994; Reed 1996). There is no central pattern generator or controller in the organism driving coordination, which, instead, is attributable to “the natural resonant properties of the body” acting in its environment (Goldfield, 1993, p. 54). The approach has been called a bottom-up approach (Burgess-Limerick et al., 1994) because it models movement organization control as emerging from the dynamic self-assembly of the units, such as the muscle motor units referred to above, of which movement is comprised (Abernethy & Sparrow, 1992).

Dynamic systems and related approaches have had much success and were particularly welcomed in developmental research (Thelen & Smith, 1994; Smith & Thelen, 1993). Roberton (1993) for example notes three points of appeal: the attempt to account for qualitative change; a ‘whole systems’ approach that also utilised models of high scientific generality; and, finally, parsimony, eliminating the need to postulate (implicitly or otherwise) internal structures or processes, such as motor programs and the like, for which there was little or no empirical evidence.

However, these approaches are not without their difficulties. One important problem is the lack of a clear theory of learning (Abernethy & Sparrow 1992; Smith & Samuelson, 2003). Research and observations showing that people can ‘overcome’ or modify the kinds of natural movement co-ordination patterns dynamic systems research was so good at accounting for also posed problems. Human walking racers, for example, have to resist the automatic transition to running that would naturally occur at the speeds they walk at, and the spatial and temporal coupling of two hands moving rhythmically can be uncoupled with continued practice (Abernethy & Sparrow, 1992; Summers & Pressing, 1994; Abernethy, et al., 2002). These problems, and more theoretical critique, have stimulated attempts to seek a rapprochement between the two paradigms.

Towards a rapprochement? If the difference between the information-processing and dynamic systems approaches is to be called a paradigm difference, then the prospects for a rapprochement should be slim if not non-existent. Abernethy and Sparrow (1992) summarized deep points of difference, noting in particular that philosophical differences (indirect versus direct realism) and the concomitant methodological implications, leading each camp to ask different and incomparable research questions (Burgess-Limerick et al., 1994; Williams et al., 1992) all point to an irreconcilable gulf.

Abernethy and Sparrow envisaged a “protracted crisis rather than rapid merger” (1992, p. 5), while Bootsma and Hardy (1997) in a paper subtitled “Half-time comments on the match” noted that there was still a deep-running controversy over which framework should be embraced.

Even in the early days of emergence of the dynamic systems view, however, Pew and Rosenbaum (1988) among others (see Abernethy & Sparrow, 1992) suggested that rather than competing to explain the same phenomena the two approaches were operating at different levels of analysis. Abernethy and Sparrow also suggested there was some evidence to support “the hybrid view of a multi-levelled motor system” (1992, pp. 31-2) with automatic control at one level (explicable in dynamic systems terms), and cognitive controls (modelled by information-processing theory) at another. In 1999, Pressing published his “referential behavior theory”, a hybrid model that he claimed was supported by existing studies and observations.

The case for a synthesis would seem to be gathering pace. Abernethy et al. (2002, p. 257) noted that a synthesis was emerging, writing: “a useful model for examining motor control in a range of coordinative tasks might be one in which control is seen to be multi-levelled, with intention (or, more generally, cognition) overriding or modifying the natural self-organising dynamics of the motor system.” Research on the control of gait in walking to running transitions designed to test the multi-level hypothesis showed that normal transitions occur spontaneously but when the normal transition was inhibited (e.g. as with walking racers) “active cognitive involvement in gait control” occurs (Abernethy et al., 2002, p. 263). The automaticity of normal walk-run transitions is consistent with dynamical systems models, but, it seems they would have difficulty coping with ‘active cognitive involvement’. A widely accepted unified theory still remains to be developed and the field is still in the midst of what perhaps can justifiably be called a paradigm crisis.

Motor skills theories and tacit knowledge

We have seen that there are few explicit references to “tacit knowledge” in research-based literature on motor skills and cognate disciplines. Davids and Myers’ (1990) paper was an appeal to sports science researchers to attend to the study of work skills where the notion of tacit knowledge had been invoked, but was largely ignored by their research community. Blais (1993, abstract), however, says there is an emphasis on “automated and tacit knowledge” in the motor domain, and much sports knowledge is probably unconscious and implicit (Williams et al., 1999) When researchers are dealing with how infants learn to crawl and walk the question of verbalizing that knowledge clearly does not arise. Overall, in so far as it has been discussed there appears to be a consensus that motor skills ‘knowledge’ is largely non-verbalizable, and thus ‘tacit’.

Much of the research into knowledge in sports discussed by Williams et al. (1999) seems to have been conducted from within the information-processing paradigm. The position of dynamic systems oriented research is more difficult to ascertain. While these theories do entertain a notion of knowledge (Smith & Samuelson, 2003) this is quite different from traditional approaches. Moreover, as we have seen, dynamic systems approaches lack a theory of learning such as could justify the idea of the ‘accumulation’ of knowledge within an organism as is characteristic of the information-processing models.

To explore the issue of whether motor skills paradigms do support the notion of tacit knowledge we have to address the question of how we can relate that research to the notion of tacit knowledge. Use of the phrase by the few writers in that field may not correspond to uses in management disciplines, while lack of use of the phrase may simply reflect a different vocabulary. One good approach, it seems, is to outline the logic of the argument for tacit knowledge, and then to see to what extent this matches any of the motor skills theories.

The logical justification for the claim that tacit knowledge exists in some sense has apparently not been set out, at least not in knowledge management literature. It seems, however, that whether we follow what we believe to be Polanyi’s arguments (since Polanyi was concerned with tacit *knowing* rather than tacit *knowledge* [Gourlay 2004b]) or take our inspiration from Wittgenstein (e.g. Collins, 1974, 2001a; Tsoukas, 2003) the logic is the same. The implicit argument is simply that if someone does something, but is unable to give an account of their actions, then they must have relied on tacit knowledge. In short, any ‘doing’ is assumed to be underpinned by knowledge of some sort, and if the agent cannot make that knowledge explicit (i.e. by verbalizing it), then self-evidently it is tacit knowledge. Thus, for example we find that when lawyers can determine critical case factors and build an argument (Marchant & Robinson, 1999), or salesmen know how to maximise situations (Wagner, Sujan, J., Sujan, M., Rachotte, & Sternberg, 1999), or scientists correctly set up an experiment (Collins, 2001b), or people apply social rules (Collins, 2001a), or nurses have correct intuitions about patients’ conditions (Herbig, Büssing & Ewart, 2001) but in none of these cases can the actors explain their behaviour, the presence and effect of tacit knowledge is invoked as a critical explanatory factor. (This logic deserves criticism, but that is not the purpose of this paper; here we are simply concerned with comparing this explanatory strategy with motor skills theories).

If we accept the above as a valid statement of the logic of ‘tacit knowledge’ explanations, then it is evident that in inferring the presence of tacit knowledge from behaviour these and other authors are following what Bechtel (1998, p. 297) called a “major strategy in cognitive science”. This consists of explaining “how ... an organism is successful in negotiating its environment by construing some of its internal states or processes as carrying information about, and so standing in for, those aspects of its body and external states that it takes account of in negotiating its environment.” It should also be apparent that this is the same explanatory strategy and central assumption as underpins the information-processing approach. Moreover, reviewing Polanyi’s arguments, it is clear they too fit this model. His central claim was that the focal object we perceive and operate with or on is constructed by internal processes of tacit inference operating on the “subsidiaries” of the focal object that we tacitly ‘take in’ (see e.g. Polanyi, 1966; 1969; Gourlay 2004b). Given the increasing dominance of the information-processing paradigm in all spheres of inquiry since the 1950s it should not be at all surprising to find that this underlies Polanyi’s arguments, nor that we are largely unaware of this fact, and that it appears as common-sense to most of us. After all, it is (still) the dominant paradigm!

The question of representations. One important area in which information-processing and dynamic systems approaches differ is that of representations, and it appears this is of particular importance as regards conceptualizing knowledge in either tacit or explicit form. In pursuing this discussion, however briefly in this context, as the issue concerns not just motor skills theories and research, but the cognitive sciences more generally (Bechtel, 1998), it becomes clear that pursuit of tacit knowledge is taking us both further afield than motor skills, and closer to knowledge management, in so far as cognitive science concepts have already informed that discipline.

Bechtel drew attention to two issues regarding representations on which dynamic systems’ views apparently diverged from or even opposed classical approaches. These are the issue of function (representations as stand-ins) and the issue of the form or format of representations. Classic cognitive science regards representations as stand-ins – they are internal states of organisms that stand in for or represent aspects of body and environment, and their relations, relevant to the organism's ability to negotiate its environment (Bechtel 1998, pp. 297-8). This has been described as the classic symbol system view of cognition (Smith & Samuelson 2003, p. 434). Dynamic systems' approaches reject this idea (Bechtel 1998, pp. 296-7, 301) but Bechtel rejected their arguments against stand-ins, concluding that dynamic systems' approaches do not offer good grounds for rejecting representations (Bechtel 1998, pp. 301-4). He admits that this entails making some very broad assumptions about representations, but, as his dynamic systems opponents did the same, he was justified in so doing (Bechtel 1998, p. 313).

As regards the format of representations, Bechtel (1998, pp. 299-300) drew attention to the significance of the distinction between representations as something *operated on* in processes, and representations *operating in* processes. The classic computational approaches to cognitive processes envisaged representations as being operated *on*, and, partly as a consequence, being propositional (Bechtel 1998, pp. 299-300). On the other hand representations that operate *in* processes, such as found in connectionist models, and in neuroscience, are non-propositional and can be dynamic (Bechtel 1998, p. 300). It would appear, as he stresses (Bechtel 1998, pp. 300, 305) "that cognitive scientists have explored a wide variety of representational formats" while proponents of the dynamic systems' views emphasis only one format. Bechtel goes further to note that some dynamic systems authors clearly do accept a notion of representations and argues that their hostility to representations probably stems from focusing on propositional type representations while they are willing to accept other, dynamic, kinds of representations. Thus, he concludes, an important contribution of dynamic systems' approaches is that they focus "on representations that change as the system evolves." (Bechtel 1998, p. 305).

Bechtel also considers another way in which dynamic systems' theorists' views on representations could be accommodated within the more traditional framework by suggesting that dynamicists repudiate high level representations, but accept low level ones. High level representations are those such as concepts designating objects in the world, linguistic symbols and the like. Simpler, lower level (i.e. more fundamental building blocks of organic behaviour) representations, or, implicitly, situations in which the objects the organism is concerned with are present (and thus do not require being represented in order for the organism to consider them) might only require dynamic representations. Dynamic systems' theorists, he suggests, might thus be making us ask whether or not high level representations are actually necessary to understanding many varieties of behaviour (Bechtel 1998, p. 305). Bechtel thus provides indirect support for the multi-level model of behavioural processes similar to that suggested by Abernethy and others, noted above.

Bechtel's arguments receive some support from two authors, one of whom (Smith) has extensively used dynamic systems models (Smith & Samuelson 2003; see e.g. Smith & Thelen 1993). Bechtel, as we have seen, suggested that connectionist and dynamic system's approaches shared the property of accepting non-propositional, dynamic, representations. Smith and Samuelson note that both connectionism and dynamic systems approaches were founded in opposition to classic cognitive science, and concur with Bechtel's argument about levels. However, they argued, instead of viewing cognition as dependent on manipulating representations both connectionism and dynamic systems view "cognition was an emergent phenomenon, grounded in lower, simpler and non-symbolic processes" (Smith & Samuelson 2003, p. 434). In the early days both these approaches eschewed representations entirely, more recently the idea of representations has received something of a reprieve, although it should be noted these are quite different from either representations as operated on or operating in. Now, claim Smith and Samuelson (2003, p. 434; their emphasis), "all that is meant by representations ... is that the *theorist* can see correspondences between internal patterns and regularities in the world." This implies that in more recent connectionist and dynamic systems models a 'representation' is simply a conceptual artefact rather than something potentially observable, or in some sense compatible with biology, 'implemented' in an organism's body, as Bechtel's argument seems to entail.

Smith and Samuelson suggest that connectionist and dynamic systems' approaches "are alike in that they are emergentist accounts and *not* representational symbol systems" (Smith & Samuelson 2003, pp. 435) but also note that they are complementary, and not identical. One important difference concerns assumptions about knowledge. For connectionists, knowledge resides in latent connections in a network that are made active by immediate input; knowledge is distributed across the network. In dynamic systems models, knowledge is emergent in the moment, "the product of the intrinsic dynamics, the state of the system at that moment, and the immediate input"; it is distributed across many kinds of processes - "perception, action, the hardness of the floor ... There is no analogue of latent knowledge ... rather knowledge is emergent in the moment, in the task, out of the particulars at hand"

(Smith & Samuelson 2003, p. 436). Thus for connectionists, 'knowledge' is 'in the organism, while for dynamicists, it is distributed across organism-environment processes; it is only 'in' the organism-environment activity unit.

Conclusions

Polanyi could be excused for speculating that motor skills were driven by tacit knowledge since research was then in its infancy. We, however, have no excuse beyond the difficulties of cross-disciplinary understanding. Motor skills, which we claim are paradigms of tacit knowledge have been studied extensively by others using more rigourous methods. Unless we wish to reject such efforts entirely we should ensure that what we say about tacit knowledge is consistent with those studies. This naturally entails the conclusion that if the notion of "tacit knowledge" turns out to be incompatible with conclusions in those fields, then we must question its continued use, except perhaps as a loose metaphor.

It would seem that the idea that actions are underpinned by some kind of knowledge that is internal to the organism owes much to, and is consistent with, the information-processing approach characteristic of traditional cognitive science, and applied to much motor skills research. Had this paper been written in the mid 1990s it would have been easy to conclude, in the then enthusiasm for the dynamic systems perspectives, that no case for tacit knowledge any longer be made because motor skills could be explained entirely without resort to any kind of representation, hence knowledge, internal to the organism. The advent of multi-level models, and clarification as regards the variety of forms 'representations' might take, makes the picture more complex.

The 'upper' levels of multi-level models implicitly involve conscious cognitive processing, which in turn implies 'knowledge' that is readily explicable – there would be no room for tacit knowledge here. The lower levels involve unconscious processing which knowledge management writers at least would interpret as dependent on tacit knowledge. However, as we have seen, the dynamic systems (and connectionist) models that are good at explaining naturally occurring unconscious movements, do so in terms inimical to any (conventional) notion of some form of knowledge held tacitly by the organism. Connectionist models could be construed in this way since for them knowledge, albeit distributed, is 'in' the organism. Dynamic systems models, however, see 'knowledge' as distributed 'across' the organism-environment boundary – in Clark's (1997, p. 53) memorable phrase, the mind is "leaky"! Both connectionists and dynamicists see knowledge as being in some sense 'dormant' until activated or evoked by the action of which it is constitutive. In other words, there no knowledge independent of the action to which the knowledge pertains and thus no "tacit knowledge" apart from activity.

Of course, it could be argued that this 'explains' why tacit knowledge cannot be explicated and is so difficult to understand – it does not exist independently of behaviour, and is not in one 'place' in an organism (or perhaps is not even wholly 'in' the organism). The view taken here, however, is that such models renders the notion irrelevant, except perhaps as a loose metaphor, reflecting the history of the knowledge management discipline.

On balance, it would seem that motor skills research does not provide support to a notion of tacit knowledge. Instead, it seems that much motor behaviour is explicable as either the emergent outcome of body-in-environment processes (not involving anything identifiable as 'knowledge') or as the result of conscious (and thus implicitly explicit knowledge using) control asserted to counter natural movement tendencies. This suggests that knowledge management practice aimed at externalizing tacit knowledge is doing nothing of the sort, but is merely collecting self-generated (or researcher generated) descriptions of aspects of work that actors are largely unaware of, or take for granted without realising their significance to someone else. If "tacit knowledge" is inseparable from the behaviour allegedly underpinned by it, then there is nothing to be 'explicated'. And, if mind, and knowledge, are 'spread' over both body and environment in ways that make it difficult to think of explicating 'knowledge' as anything other than a limited form of abstraction from a dynamic process.

A more radical implication is that perhaps we should start to take seriously models of behaviour that use the organism-in-environment unit of analysis, such as ecological psychology, situated cognition, and dynamic systems approaches. Rather than focusing on individuals out of context, or only seeing individuals as interacting with (but not fundamentally influencing, or being influenced by) their environment, we should see individual and environment as mutually constraining and enabling.

References

Abernethy, B., Hanna, A., & Plooy, A. (2002). The attentional demands of preferred and non-preferred gait patterns. *Gait and Posture, 15*, 256-265.

Abernethy, B., & Sparrow, W. A. (1992). The rise and fall of dominant paradigms in motor behaviour research. In J. J. Summers (ed.), *Approaches to the study of motor control and learning* (pp. 3-45). Amsterdam, London: North-Holland.

Ambrosini, V., & Bowman, C. (2001). Tacit knowledge: Some suggestions for operationalization. *Journal of Management Studies, 38*(6), 811-829.

Argote, L., & Ingram, P. (2000). Knowledge transfer: a basis for competitive advantage in firms. *Organizational Behavior and Human Decision Processes, 82* (1), 150-169.

Baumard, P. (1999). *Tacit knowledge in organizations*. London & Thousand Oaks: Sage.

Bechtel, W. (1998). Representations and cognitive explanations: assessing the dynamicist's challenge in cognitive science. *Cognitive Science, 22*(3), 295-317.

Blais, C. (1993). Concept mapping of movement-related knowledge. *Perceptual & Motor Skills, 76*(3 Pt 1), 767-74.

Bootsma, R. J., & Hardy, L. (1997). Perception and action in sport: half-time comments on the match. *Journal of Sports Sciences, 15*, 641-642.

Burgess-Limerick, R., Abernethy, B., & Limerick, B. (1994). Identification of underlying assumptions is an integral part of research: An example from motor control. *Theory & Psychology, 4*(1), 139-146.

Carello, C., Turvey, M. T., Kugler, P. N., & Shaw, R. E. (1984). Inadequacies of the computer metaphor. In M. S. Gazzaniga (ed.), *Handbook of cognitive neuroscience* (pp. 229-248). New York, London: Plenum Press.

Clark, A. (1997). *Bring there. Putting brain, body, and world together again*. Cambridge, MA; London: A Bradford Book; MIT Press.

Clark, J. E., Truly, T. L., & Phillips, S. J. (1993). On the development of walking as a limit-cycle system. In L. B. Smith, & E. Thelen (eds), *A dynamic systems approach to development. Applications* (pp. 71-93). Cambridge, MA; London: A Bradford Book, MIT Press.

Collins, H. M. (1974). The TEA set: tacit knowledge and scientific networks. *Science Studies, 4*, 165-186.

Collins, H. M. (2001a). What is tacit knowledge? In T. R. Schatzki, K. Knorr Cetina, & E. von Savigny (eds), *The practice turn in contemporary theory* (pp. 107-119). London and New York: Routledge.

Collins, H. M. (2001b). Tacit knowledge, trust, and the Q of sapphire. *Social Studies of Science, 31*(1), 71-85.

Davids, K., & Myers, C. (1990). The role of tacit knowledge in human skill performance. *Journal of Human Movement Studies, 19*, 273-288.

Donaldson, L. (2001). Reflections on knowledge and knowledge-intensive firms. *Human Relations, 54*(7), 955-963.

Doyle, A. J. R. (1988). *The skill of bicycle riding*. Unpublished doctoral dissertation, Sheffield.

Easterby-Smith, M., & Lyles, M. A. (2003). Introduction: watersheds of organizational learning and knowledge management. In M. Easterby-Smith, & M. A. Lyles (eds.), *The Blackwell Handbook of Organizational Learning and Knowledge Management* (pp. 1-15). Malden, MA; Oxford: Blackwell Publishing Ltd.

Gallahue, D. L., & Ozmun, J. C. (1998). *Understanding motor development. Infants, children, adolescents, adults* (4th ed.). Boston, MA: McGraw Hill.

Goldfield, E. C. (1993). Dynamic systems in development: action systems. Chapter 2 in L. B. Smith, & E. Thelen (eds), *A dynamic systems approach to development. Applications* (pp. 51-70). Cambridge, MA: London: The MIT Press.

Gourlay, S. N. (2004a). 'Tacit knowledge': the variety of meanings in empirical research. Fifth European Conference on Organizational Knowledge, Learning and Capabilities Innsbruck, Austria, 2-3 April (http://www.ofenhandwerk.com/oklc/pdf_files/B-2_gourlay.pdf).

Gourlay, S. N. (2004b). Knowing as semiosis: steps towards a reconceptualization of 'tacit knowledge. In H. Tsoukas, & N. Mylonopoulos (eds), *Organizations as Knowledge Systems* . London: Palgrave Macmillan.

Handford, C., Davids, K., Bennett, S., & Hutton, C. (1997). Skill acquisition in sport: some applications of an evolving practice ecology. *Journal of Sports Sciences, 15*, 621-640.

Herbig, B., Büssing, A., & Ewert, T. (2001). The role of tacit knowledge in the work context of nursing. *Journal of Advanced Nursing, 34*(5), 687-695.

Janik, A. (1988). Tacit knowledge, working life and scientific method. In B. Göranzon, & I. Josefson (eds), *Knowledge, skill and artificial intelligence* (pp. 53-63). London & Berlin: Springer-Verlag.

Kelso, J. A. S. (1982a). The process approach to understanding human motor behavior: an introduction. In J. A. S. Kelso (ed.), *Human motor behavior. An introduction* (pp. 3-19). Hillsdale, NJ; London: Lawrence Erlbaum Associates.

Kelso, J. A. S. (1982b). Epilogue: two strategies for investigating action. In J. A. S. Kelso (ed.), *Human motor behavior. An introduction* (pp. 283-287). Hillsdale, NJ; London: Lawrence Erlbaum Associates.

Laszlo, J. I. (1992). Motor control and learning: how far do the experimental tasks restrict our theoretical insight? In J. J. Summers (ed.), *Approaches to the study of motor control and learning* (pp. 47-79). Amsterdam, London: North-Holland.

MacKenzie, D. (1996). *Knowing Machines: Essays on Technical Change*. Boston, MA: MIT Press.

Marchant, G., & Robinson, J. (1999). Is knowing the tax code all it takes to be a text expert? On the development of legal expertise. In R. J. Sternberg, & J. A. Horvath (eds), *Tacit knowledge in professional practice* (pp. 3-20). Mahwah, NJ and London: Lawrence Erlbaum Associates.

Meijer, O. G. (1988). *The hierarchy debate: perspectives for a theory and history of movement science*. Amsterdam: Free University Press.

Nonaka, I., & Takeuchi, H. (1995). *The knowledge-creating company*. New York, Oxford: Oxford University Press.

Pew, R. W., & Rosenbaum, D. A. (1988). Human Movement Control: computation, representation, and implementation. In R. C. Atkinson, R. J. Herrnstein, G. Lindzey, & R. D. Luce (eds), *Steven's*

Handbook of experimental psychology (Vol. 2pp. 473-509). New York, Chichester: John Wiley & Sons.

Pleasants, N. (1996). Nothing is concealed: de-centring tacit knowledge and rules from social theory. *Journal for the Theory of Social Behaviour, 26*(3), 233-255.

Polanyi, M. (1962). *Personal knowledge. Towards a post-critical philosophy*. Chicago & London: Chicago University Press.

Polanyi, M. (1966). *The Tacit Dimension*. London: Routledge & Kegan Paul Ltd.

Polanyi, M. (1969). The Logic of Tacit Inference. In M. Grene (ed.), *Knowing and Being. Essays.* (pp. 138-158). London: Routledge and Kegan Paul.

Pressing, J. (1999). The referential dynamics of cognition and action. *Psychological Review, 106*(4), 714-747.

Reed, E. S. (1996). *Encountering the world. Toward an ecological psychology*. New York, Oxford: Oxford University Press.

Roberton, M. A. (1993). New ways to think about old questions. In L. B. Smith, & E. Thelen (eds), *A dynamic systems approach to development. Applications* (pp. 95-117). Cambridge, MA: London: The MIT Press.

Schmidt, R. A. (1982a). More on motor programs. In J. A. S. Kelso (ed.), *Human motor behavior. An introduction* (pp. 189-217). Hillsdale, NJ; London: Lawrence Erlbaum Associates.

Schmidt, R. A. (1982b). The schema concept. In J. A. S. Kelso (ed.), *Human motor behavior. An introduction* (pp. 219-235). Hillsdale, NJ; London: Lawrence Erlbaum Associates.

Smith, L. B., & Samuelson, L. K. (2003). Different is good: connectionism and dynamic systems theory are complementary emergentist approaches to development. *Developmental Science, 6*(4), 434-439.

Smith, L. B., & Thelen, E. (1993). *A dynamic systems approach to development. Applications*. Cambridge, MA; London: The MIT Press.

Spender, J.-C. (1996). Competitive advantage from tacit knowledge? Unpacking the concept and its strategic implication. In B. Moingeon, & A. Edmondson (eds), *Organizational learning and competitive advantage* (pp. 56-73). London & Thousand Oaks: Sage.

Stelmach, G. E. (1982). Motor control and motor learning: the closed-loop perspective. In J. A. S. Kelso (ed.), *Human motor behavior. An introduction* (pp. 93-115). Hillsdale, NJ; London: Lawrence Erlbaum Associates.

Summers, J. J. (1992). Movement behaviour: a field in crisis? In J. J. Summers (ed.), *Approaches to the Study of Motor Control and Learning* (pp. 551-562). Amsterdam, London: North-Holland.

Summers, J. J., & Pressing, J. (1994). Coordinating the Two Hands in Polyrhythmic Tapping. In S. P. Swinnen, J. Massion, H. Heuer, & P. Casaer (eds), *Interlimb coordination: nerual, dynamical, and cognitive constraints* (pp. 571-593). San Diego, New York: Academic Press.

Thelen, E., & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action*. Cambridge, MA.: MIT Press.

Tsoukas, H. (2003). Do we really understand tacit knowledge? In M. Easterby-Smith, & M. A. Lyles (eds.), *The Blackwell Handbook of Organizational Learning and Knowledge Management* (pp. 410-427). Malden, MA; Oxford: Blackwell Publishing Ltd.

Turvey, M. T., Fitch, H. L., & Tuller, B. (1982). The Bernstein perspective: I. The problems of degrees of freedom and context-conditioned variability. In J. A. S. Kelso (ed.), *Human motor behavior. An introduction* (pp. 239-252). Hillsdale, NJ; London: Lawrence Erlbaum Associates.

Wagner, R. K., Sujan, J., Sujan, M., Rashotte, C. A., & Sternberg, R. J. (1999). Tacit knowledge in sales. In R. J. Sternberg, & J. A. Horvath (eds), *Tacit knowledge in professional practice* (pp. 155-182). Mahwah, NJ and London: Lawrence Erlbaum Associates.

Williams, A. M., Davids, K., L. Burwitz, L., & Williams, J. G. (1992). Perception and action in sport. *Journal of Human Movement Studies, 22*, 147-204.

Williams, A. M., Davids, K., & Williams, J. G. (1999). *Visual perception and action in sport.* London and New York: E & F Spon.

Wolpert, D. M., Ghahramani, Z., & Flanagan, J. R. (2001). Perspectives and problems in motor learning. TRENDS in Cognitive Sciences, 5(11), 487-494.